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Avoiding a Hollow Force: An Examination of Navy Readiness

Matthew T. Robinson • James M. Jondrow •
Laura J. Junor • Jessica S. Oi

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Samuel D. Kleinman, Director
Infrastructure and Readiness Team
Support Planning and Management Division

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Since 1989, the Navy has decommissioned 165 ships, seen its endstrength fall by nearly a quarter, and had its budget reduced by $38 billion -- a net reduction of 32 percent. These cuts have raised fears that the Navy may once again be on the verge of a hollow force. Our review of the readiness literature suggests that hollowness is a condition that keeps ships from living up to their design potential. It is the general state that persists whenever maintenance problems dominate a force; when poor quality sailors seem the rule rather than the exception; and when meaningful training is both scarce and questionable. In the 1970s and early 1980s, the Navy experienced all of these problems and more. This paper summarizes the stages of our work on this issue and discusses the insights and key findings we have made along the way.

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Contents

Summary

This research memorandum focuses on work CNA has done over the past year and a half regarding Navy readiness. The goal of this work has been to create management tools so the Navy can better monitor, track, and predict readiness. The tools we suggest the Navy use fall into two broad categories:

- Those that help measure readiness—so that senior leaders can get a "big picture" assessment of current readiness status
- Those that help explain and understand what drives readiness.

Our approach has been to focus on indicators of readiness that have objective data behind them. These are important because readiness is an intangible quality that can only be measured indirectly. In this sense, readiness is analogous to personnel intelligence. Collecting tangible indicators gives us a clue to what readiness really looks like.

Measurement

What makes an indicator useful? We conclude that the primary factor is a long track record. Data starting in 1994 is much less useful than data going back to 1977. The Navy should always look for new indicators, but it may be even more important to develop and interpret historical track records. New indicators, however, will be of little use unless the data is archived in a way that will allow historical comparison at some future time. In our study, we amassed more than a hundred indicators of Navy readiness dating back nearly 20 years. Such trendlines are crucial for:

- Benchmarking readiness—judging current status against some standard, such as the good and bad times of the past
- Summarizing readiness—combining long lists of indicators into interpretable indexes

- Predicting readiness—explaining the effect that one resource area (such as personnel quality) has on other resource areas.

This paper summarizes how we have approached these tasks and integrated them into a coherent strategy for avoiding a hollow force.

Background

Over the past several years, there has been growing concern among Navy leaders that reduced defense spending and rising commitments may be creating another hollow force. We surveyed 64 Navy leaders (flag officers, Assistant Secretaries of the Navy, and senior enlisted personnel) and discovered that most remember the period after the Vietnam War as a period characterized by hollowness. It was, in their view, a time when the Navy:

- Could not sustain itself
- Had high levels of drug use and discipline problems
- Lacked proper equipment
- Had too few experienced enlisted personnel.

By mid 1994, these leaders were worried about a different set of problems. They worried about the effect current operations were having on a smaller but ready force. They also worried about rising maintenance backlogs, decreasing training time, and shrinking modernization accounts. But most of all, they worried about the quality of the sailor serving today. To many, quality personnel was the one factor that lessened the impact of all their other worries.

This concern led the Navy to ask CNA to help it develop better ways to measure readiness and identify possible predictors of future readiness. One goal of this work has been to develop tools that would "enable us to see potential problems in sufficient time to take corrective action" [1].

General findings

By and large, the Navy has an extremely high level of readiness today. This is particularly evident in terms of personnel quality, which has driven improvements in other areas of the Navy as well. An index of personnel quality, which bundles together a variety of readiness indicators, shows personnel quality today to be higher than it has ever been (at least dating back to 1977).

Below, we summarize these and other substantive findings:

- *Readiness is not an empty concern.* Historical evidence suggests that hollowness tends to follow downsizing. There have been specific instances of unreadiness in the past, and these have forced us to order troops into battle unprepared and with tragic consequences.
- *Readiness tends to move in long slow cycles.* Current data show a general upward trend. Month-to-month movements are not always meaningful—Navy leaders should not overreact to these fluctuations.
- *SORTS—the Status of Resources and Training System—is a useful measure of readiness.* Measures of readiness based on SORTS parallel more objective indicators—which tends to substantiate SORTS.
- *The different SORTS resource areas are intertwined.* These areas are training, supply, personnel, and equipment. Personnel has a direct effect on all resource areas. Supply and equipment have indirect effects on training readiness.

Methodological findings

Our work has illustrated the value of using a variety of methods to help answer persistent readiness problems such as the following:

- *How can a number of indicators be consolidated into one or a few indexes?* Indexing is a useful technique for summarizing the movements of many indicators over time. It also holds great promise for summarizing otherwise hard-to-measure areas. We

used a weighted average formed using a statistical technique called principal component analysis. We illustrate this technique by forming an index of personnel quality. The Navy should maintain and expand upon this index.

- *How are different indicators of readiness linked?* Readiness can be explained through the use of statistical models. We first constructed a series of equations to test the hypothesis that various resource areas were linked to readiness. We then converted these theoretical equations to numerical ones using statistical techniques, such as regression analysis. These techniques, when applied to quarterly data from individual surface combatants, formed the basis of our model.

- *What are the standards used to evaluate whether a specific level of readiness is good or bad?* Using techniques that merge several readiness indicators, we can compare today's readiness to that of previous periods. A "cluster" of indicators can give a far clearer picture of readiness than individual measures. The readiness clusters that we formed showed that current data look nothing like data from the late 1970s and early 1980s.

- *How can we measure the direction in which readiness is moving?* Although readiness tends to move up or down—in a linear sense, there is a multifaceted dimension to this movement. Not all resource areas move together at the same speed. We compared the recent move (from the mid 1980s to the recent period) with the initial move out of hollowness (the move from the early 1980s to the mid 1980s). We found that the recent move was carrying us further away from hollowness, but was in a different way than the initial move out of hollowness.

- *How can readiness be forecast?* By examining the timing aspect of statistical models—when one indicator affects another—we can begin to identify early warning signs of future readiness problems. Trends and cycles around the models' statistical predictions can further help us forecast.

- *How can hollowness be prevented?* Preventing hollowness involves both forecasting and reacting rapidly to current deficiencies. The mix between these two strategies depends on how fast the

Navy can react and the accuracy of the forecast. If the Navy can develop the flexibility to respond quickly to readiness problems, it will be less necessary to depend on forecasts—which will always be highly imperfect.

Introduction

Since 1989, the Navy has decommissioned 165 ships, seen its endstrength fall by nearly a quarter, and had its budget reduced by $38 billion—a net reduction of 32 percent. These cuts have raised fears that the Navy may once again be on the verge of a hollow force. Our review of the readiness literature suggests that hollowness is a condition that keeps ships from living up to their design potential. It is the general state that persists whenever maintenance problems dominate a force; when poor quality sailors seem the rule rather than the exception; and when meaningful training is both scarce and questionable. In the 1970s and early 1980s, the Navy experienced all of these problems and more. It was a tough time.

How did it happen? Hollowness in the 1970s had many possible causes, including:

- Low public support for the military
- Pressure to cut defense spending
- Difficulties in maintaining an all-volunteer force, i.e., failure to attract and retain high-quality recruits
- Declining pay
- Poor morale
- Delays in fielding modern armaments and equipment
- Inadequate attention to maintenance of existing equipment.

These problems seem to be related to our involvement in Vietnam. Because the military of this era was not viewed as an attractive career option, none of the Services had much luck in accessing quality recruits. Without good people, it was hard to mold future senior enlisted leaders. The shortage of petty officers in the late 1970s and early 1980s—which so many associate with hollowness—may have been the consequence of society's general aversion to the military in the wake of Vietnam. But there is

no guarantee that hollowness will affect us the same way twice. Indeed, it may well catch us next where we least expect it. This is what this paper is about—ways to understand and avoid hollowness.

The present drawdown

In the past 6 years, ever since the Berlin Wall fell, the Department of the Navy's (DON's) budget has dropped 32 percent after adjusting for inflation. This reduction has largely been borne by the Navy's procurement account (which has fallen by 65 percent from its 1989 level). The total reduction is big—about 11 percent greater than the percentage cut the DON's budget took between 1968 and 1975. One repercussion of this large cut is that the Navy's operations and maintenance (O&M) account—which is often described as the readiness account—is now falling about twice as fast as it fell during the previous drawdown. When we look a little more closely at this phenomenon, we find the ratio between O&M and ships to be roughly the same today as it was in the 1980s and roughly 14 percent larger than it was in the mid- to late 1970s.

Table 1. Total DON percentage increases and decreases during two latest periods of downsizing

	1968-75	1989-95
Forces		
Ships	-39	-44
Aircraft	-31	-24
Personnel		
Military	-32	-22
Civilian	-24	-31
Budget (C$)		
Personnel	-27	-20
O&M	-13	-29
Procurement	-26	-65
RDT&E	+3	-20

What's interesting about this is that, in terms of tangible things, i.e., ships and aircraft, the present drawdown looks very similar to the one that led to "classical hollowness." Indeed, the funding that present forces depend on is now falling faster than it did in the early 1970s—even though the O&M-to-ships ratio seems rather robust (at least as judged by the levels seen in the 1980s).

These cutbacks bring with them the fear that readiness—the maintenance of appropriate levels of manning, training, and equipment procurement, distribution, and maintenance—will ultimately suffer. This is a possibility that Navy leaders do not take lightly. Senior Navy officials lived through the hollow period of the 1970s and will not quietly let ships and aircraft slip back into this state.

A possible response

As a consequence, over the last several years Navy leaders have made it a top priority to keep readiness strong, even building into their annual budgeting process a separate assessment of the adequacy of readiness-related funding. They also have begun to think about the many different indicators that are available to help inform them about readiness. How many are there? What kind of data do they contain? Who uses them? What is their relationship to one another? And perhaps most importantly, can they help forecast future readiness problems? In an attempt to come to grips with these issues, the Office of the Chief of Naval Operations asked CNA to identify trends and develop predictors using available readiness indicators. We approached this problem in three phases.

Phase one: Define readiness

First, we spent considerable time defining readiness in all its many dimensions. This was an important step because it focused us on the phenomena of readiness itself—what it means to be ready and how we could capture this concept in quantifiable form. This turned into quite a challenge because few people think of readiness in exactly the same way.

Phase two: Measure readiness

After satisfying ourselves that we knew what we were looking for, we moved on to the second stage of our work—measuring readiness. This involved identifying pertinent indicators, collecting available data, examining trendlines, and proposing ways to summarize a wide range of indicators. From this, we became familiar with the general readiness condition of the Navy—not just in terms of current status but also in relation to past conditions as well.

Phase three: Predict readiness

We then began the third stage of our work: predicting readiness. This part of the project involved uncovering the various causal relationships that individual indicators exhibited and the effect they have on overall performance. As a step in this direction, we began developing a model that highlights the interdependencies that characterize various facets of ship readiness.

Organization

In the sections that follow, we describe the progress we have made at each stage of our work and discuss the insights and key findings we have made along the way. Footnotes contain reference citations directing readers to more detailed documentation of our work.

Defining readiness

Readiness has been used rather liberally to refer to a wide range of military-related activities. When professionals speak of readiness, they are generally referring to whether a military force has all its component parts in good working order. The emphasis is on existing rather than prospective forces and their ability to deploy on notice and employ effectively on arrival. This generally means having the following assets on hand:

- Sufficient numbers of high-quality personnel
- Well maintained and ready equipment
- Units that are properly supplied
- Effective training programs.

This definition is formerly codified in the Department of Defense (DOD) Dictionary of Military and Associated Terms (JCS Pub 1-02), which defines readiness as but one of four critical components that form military capability— "the ability to achieve a specified wartime objective." In it, DOD refers to readiness as "the ability of forces, units, weapons systems, or equipments to deliver the outputs for which they were designed" [2].

Relationship to hollowness

Many think of hollowness and readiness as opposites—if you are not ready, then you must be hollow. We reviewed a wide range of material relating to readiness, to include the public statements of key military and political leaders [3]. This review does not support the view that the two are opposites. Indeed, it tells us rather definitively that hollowness is an umbrella term, closely related to deficiencies in overall capability, or big "R" as some have called it, whereas readiness, or little "r," is a narrower concern that refers to whether military systems

(both people and equipment) can do what they are designed to do—as in the above definition.

This is contrary to the view of hollowness first espoused by Army General Edward C. "Shy" Meyer in the early 1980s to refer to the state of the Army at that time. The image he invoked was of an Army somewhat misleading in appearance—robust to outsiders in terms of the number of divisions it could field but weak on the inside. It was, in his opinion, a misleading force—incapable of doing certain basic things that others expected of it. Therefore, many now view hollowness as a way to describe an unready force—one whose systems cannot function as intended and whose people are not as bright or fully trained as they should be.

Historical hollow forces

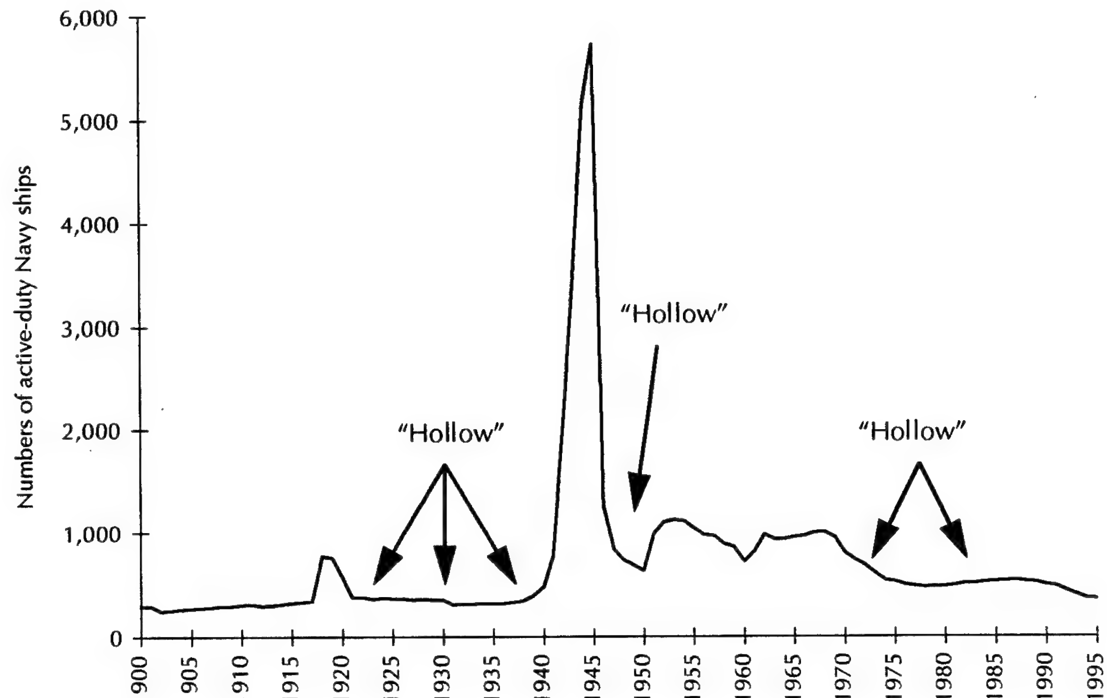
A review of recent American military history shows that hollow forces exhibit symptoms of both insufficient size and reduced readiness.[1] We describe as "hollow" any force in which there is a serious degradation of military capability. This condition tends to occur more often after periods of major downsizing. This was the case during the Interwar Years (1920s–1930s), the post-World War II period (1945–1950), and following Vietnam (1968–75). Figure 1 portrays these periods on a graph. Each time we downsized, a host of problems ensued—some we now consider classic readiness problems, but others were more closely linked to lack of force size and inadequate modernization efforts. Our review suggests the following:

- First, hollowness is a real concern. It has happened before and could happen again.
- Second, hollowness does seem related to the drawdown of forces. Bringing the force down in an intelligent way is important—as is the desire to keep what remains in top fighting trim. The goal is to reduce and restructure forces in a way that allows the Navy to maintain adequate capability. But managing this process is hard, and it

1. Documentation provided in CNA Research Memorandum 95-12, *Defining the Hollow Force: Is It More Than Just a Readiness Problem?* By Matthew T. Robinson, April 1995.

often creates turbulence—units that move from one place to another, some that fold into others; quality people who leave that otherwise might remain; a promotion process that slows to a crawl. These problems prove difficult to contain and far too often lead to others, which are equally hard to solve.

Figure 1. Total active-duty ships in the U.S. Navy, 1900–1995, and corresponding hollow periods



- Third, hollowness could occur at inopportune moments, which force us to order troops into battle unprepared and with tragic consequences. That is the lesson of our early defeats in World War II and Korea. During times of reduced threat, we often feel we can get by with less capability. This constitutes hollowness only when it is viewed as a deficiency. The 1930s, for example, can be considered hollow only in comparison to what happened in 1941 or, conversely, what might have happened

sooner. Likewise, our pre-Korean forces can be considered hollow only when judged in light of what happened later. To the extent that no real test is likely, a certain amount of hollowness is not necessarily a bad thing, even if it cannot be considered desirable. The trick is to watch the developing threat carefully and react before it becomes serious.

- Fourth, we managed to avoid hollowness only once following the conclusion of a major war. This occurred after Korea and seems unique to this period. The reasons behind this are fairly straightforward: The severity of the drawdown that followed Korea was not as great as previous ones; the emergence of the Soviets as a real threat meant that readiness had to be protected; and the absence of an immediate test—like Pearl Harbor or July 1950—meant that forces of this era never had to perform up to their full design potential.
- Finally, hollowness has size, quality, and time dimensions. Readiness deficiencies alone do not account for why a given force goes hollow. Total numbers do matter. One consequence of this is that it takes time to rebuild disassembled forces. We did not climb out of the hollowness of the 1970s until the 1980s were well under way. Such a time lag can prove costly if forces are required to perform as if they are solid before the retooling phase is complete.

Surveying senior leaders

Because hollowness is a complex subject and readiness a particularly thorny aspect of it, OPNAV asked us to consider the views of senior naval leaders whose experiences might prove useful in identifying worthwhile indicators of impending hollowness.[2] Specifically, we were asked to design and administer a survey that would answer the following questions:

2. Documentation provided in CNA Research Memorandum 94-167, *Hollowness and the Navy: Interviews with Senior Navy Leaders*, by Matthew T. Robinson, et al., November 1994.

- What does a hollow force mean? What did the last hollow force look like? Is the Navy going hollow again? If so, how quickly are we approaching this state?
- What types of readiness indicators should the Navy be looking at? What do these indicators tell us about the current state of the Navy? What kind of information can we realistically expect to get out of a readiness indicator?
- Where is hollowness most likely to occur? How can we prevent it from setting in? Are there factors, outside of funding, that make it hard to avoid hollowness? If so, what are they?

In the summer of 1994, we administered the survey to more than 66 of the Navy's highest ranking officials, including 3 assistant secretaries of the Navy, 50 flag officers, and 4 force master chiefs [4]. By and large, they felt that the overall readiness of the fleet was good. The quality of people in the Navy today was at an all-time high, and the equipment they use is the best in the world. Still, some were deeply troubled by recent events. Many felt that readiness was slipping and that current operations were sapping time and money from other important areas. Many pointed out that maintenance backlogs were on the rise, interdeployment training was slipping, key modernization programs were being cut, and real-property maintenance was being deferred. To many, these are signals that the Navy is overstretched, and they create the perception that, unless present trends are reversed, the Navy could once again find itself hollow.

Personnel issues dominated most of our discussions. Table 2 documents these results. Roughly one-third of everyone we spoke with considered the quality of sailors serving as the key element in avoiding a hollow force. As several suggested, a "good" sailor can make up for deficiencies in other areas and is smart enough to come up with solutions when none are thought possible. This, to many, defined a quality force.

Still others felt that total manning was more important than personnel quality. They did not think that quality was unimportant, just that quantity was more important, at least in relative terms.

Others expressed concern that a preoccupation with people could lead the Navy away from areas where hollowness is most likely to occur. A military force can decay in any number of interrelated areas, and there is no guarantee that the next hollow force will look like the last one. Many of these individuals focused on other areas thought to be important, including flying/steaming hours, training support, and available spares.

Table 2. Critical elements in preventing a hollow force[a]

	First	In top three
Personnel quality	24	40
Total manning	8	19
Retention	3	18
Flying/steaming	5	16
Training	2	21
Spares	2	15
O-level maintenance	2	10

a. Column one shows the number of people (out of the 66 surveyed) who identified the particular issue as most critical to avoiding hollowness; column two shows the number of people who identified it as one of their three most critical elements.

An underlying theme in many of our discussions was the importance of morale as a general indicator of a force's readiness. Many felt that morale was a function of the quality of work sailors perform, the tools they are given, and the recognition they receive. When fast OPTEMPO causes equipment to break down, spares grow scarce and training time suffers. Soon, work becomes harder; people get frustrated; and some start thinking about finding another profession. Few felt that the Navy does a good job of measuring these factors, and yet nearly everyone we spoke with thought the ability to do so was vital to preserving readiness.

Insights *(for avoiding a hollow force)*

Some things stand out in terms of the importance of avoiding a hollow force. These include the notion that hollowness is a real concern. It has happened before and it could happen again. It is not

something that should be ignored. What's more, hollowness has serious consequences. People have lost their lives because we failed to avoid it in the past.

Second, there is no guarantee that readiness deficiencies alone will cause hollowness. It is just as likely to afflict a force that is well-manned, well-trained, and well-equipped as it is a force that lacks these attributes. Size plays a role in this and should be watched closely. In this paper, however, we focus almost exclusively on questions of readiness. But avoiding hollowness is as much about preserving adequate force structure as it is about preserving readiness. This suggests that what we need to do is find ways to identify the appropriate balance between competing resource requirements and find ways to understand the tradeoffs associated with funding one area versus another.

Third, many view high personnel quality as the key to avoiding hollowness. If personnel quality stays high, problems in other areas can be contained—even avoided. Hollow forces tend to be associated with low morale, disciplinary problems, and even substance abuse. One concern is that it does not appear that personnel quality can change overnight. If the quality is low, it could take several years to correct.

Finally, hollowness seems to be closely connected with the amount of resources that a force has at its disposal. If resources are plentiful, hollowness is not much of a concern. But when they are tight, people worry about the consequences. This suggests that indicators that capture the adequacy of on-hand resources may offer clues as to pending hollowness. If indicators suggest that resources are sufficient, then hollowness is not a worry.

Measuring readiness status

Readiness has proven difficult to measure, in part because it is an intangible quality; people can't readily see it or measure it in an objective way. Indeed, it is much like intelligence, something we can only measure indirectly through certain actions we assume smart people are capable of performing. For example, we only know whether a ship is ready or not based on the percentage of personnel on board as a fraction of those the ship should have; the total number of combat systems that are up and running, again as a fraction of those the ship needs to perform its mission; and the total amount of training performed, as a fraction of the training an experienced commander believes is essential to accomplish the mission.

As we have seen, the definition of readiness refers to the extent to which systems (equipment, people, forces, etc.) can perform up to their design potential. This definition seems to suggest a measure based on repeated observations of the system in operation, for instance, exercise results. In practice, this has not been easy. The reasons are obvious:

- Missions and scenarios change over time so there would be no continuity to this measure.
- Observations themselves tend to be highly subjective.
- Unit commanders are not apt to willingly advertise readiness deficiencies.

One consequence is that direct measures of readiness—operational outputs—are hard to find. So instead of using performance data, many analysts tend to rely on indirect measures to assess readiness. Usually, this involves collecting information on physical assets such as numbers of operational aircraft, stocks of spare parts, and fully manned billets. One problem with such measures is that they are both

"outputs" and "inputs" into other measures as well, which makes it ever harder to distinguish between cause and effect.[3]

Typical measures of readiness

Most of the readiness systems in place today focus on straightforward compilations of assets against required levels. They ask basic questions about what, where, and general condition. These measures are designed to gauge the initial capability of units and forces, not their design potential.

SORTS

The Status of Resources and Training System (SORTS) is probably the most widely recognized source of information about unit readiness status. It contains detailed information about the amount and condition of personnel and equipment resources a unit possesses and the status of its training. SORTS assigns a grade—referred to as "C-level"—for the status of a unit's resources relative to requirements. There are five overall status categories:

- C1—Unit possesses the required resources and is trained to undertake the full wartime mission for which it is organized or designed.
- C2—Unit possesses the resources and has accomplished the training necessary to undertake the bulk of the wartime mission for which it is organized or designed.
- C3—Unit possesses the resources and has accomplished the training necessary to undertake major portions of the wartime mission for which it is organized or designed.
- C4—Unit requires additional resources and/or training in order to undertake its wartime mission, but if the situation dictates, it may be directed to undertake portions of its wartime missions with resources on hand.

3. Some studies have taken a different tact, choosing to focus on performance-based data. See [14, 23, 25, 26, 27].

- C5—Unit is undergoing a service-directed resource change and is not prepared, at this time, to undertake the wartime mission for which it is organized or designed. (C5 for a Navy ship generally means that it is undergoing overhaul.)

Grades are assigned for each of four resource categories—personnel, equipment, supply, and training. There is also an overall score, which within the Navy reflects the lowest of the four resource categories. When a ship deploys, it is expected to have an overall rating of at least C2 [5].

No one believes SORTS is a perfect system. Although it clearly signals which units are the best equipped, manned, and trained, it is often criticized as subjective, gameable, and incomplete. SORTS contains no information about what units can do (their outputs) or how well they can do it; it only contains information about assets on hand. The requirements against which assets are judged tend to be arbitrary—they change as equipment, employment plans, and training doctrine evolve.[4] They also tend to reflect the most demanding operational contingency possible—so that poor SORTS scores may actually mean that a unit is very capable of handling a number of lesser missions. Finally, SORTS treats all resource categories as equally important—a somewhat dubious way of determining readiness status because it's not always clear whether something that is missing is needed for the job at hand.

Despite these shortcomings, SORTS is the most commonly used proxy for unit readiness. All the Services, including the Joint Staff, make detailed presentations to senior leaders using information from SORTS. It is also one of the few indicators with a long track record. Thus, we believe it is important to understand its behavior over time.

To find out what SORTS tells us about past Navy readiness, we looked at the percentage of time the average surface combatant spent in C1 or C2 for every month from 1977 to the end of 1994. Figure 2 shows

4. For example, a new weapon system requirement might cause a unit's SORTS category level to rise from C2 to C1, but that unit would be no more capable than before the change. This tendency to redefine SORTS requirements as the threat changes only frustrates analysts charged with comparing SORTS levels from one time to another.

the data. The top data points represent deployed surface combatants; those on the bottom represent nondeployed surface combatants. The symbols scattered across the figure represent the percentage of time the average surface combatant spends in C1 or C2 in a given month. The shape of the symbol corresponds to the lowest reported resource area—i.e., the one dragging the percentage of time spent in C1 or C2 down.[5] The black lines represent a smoothing technique—a seventh order polynomial—that helps focus attention on the direction in which the curve is moving. This polynomial closely approximates a 24-month moving average of the data.

Despite many inconsistencies in how SORTS data are reported, this figure can tell us a lot about Navy readiness over the past 15 years.

Cycles of readiness

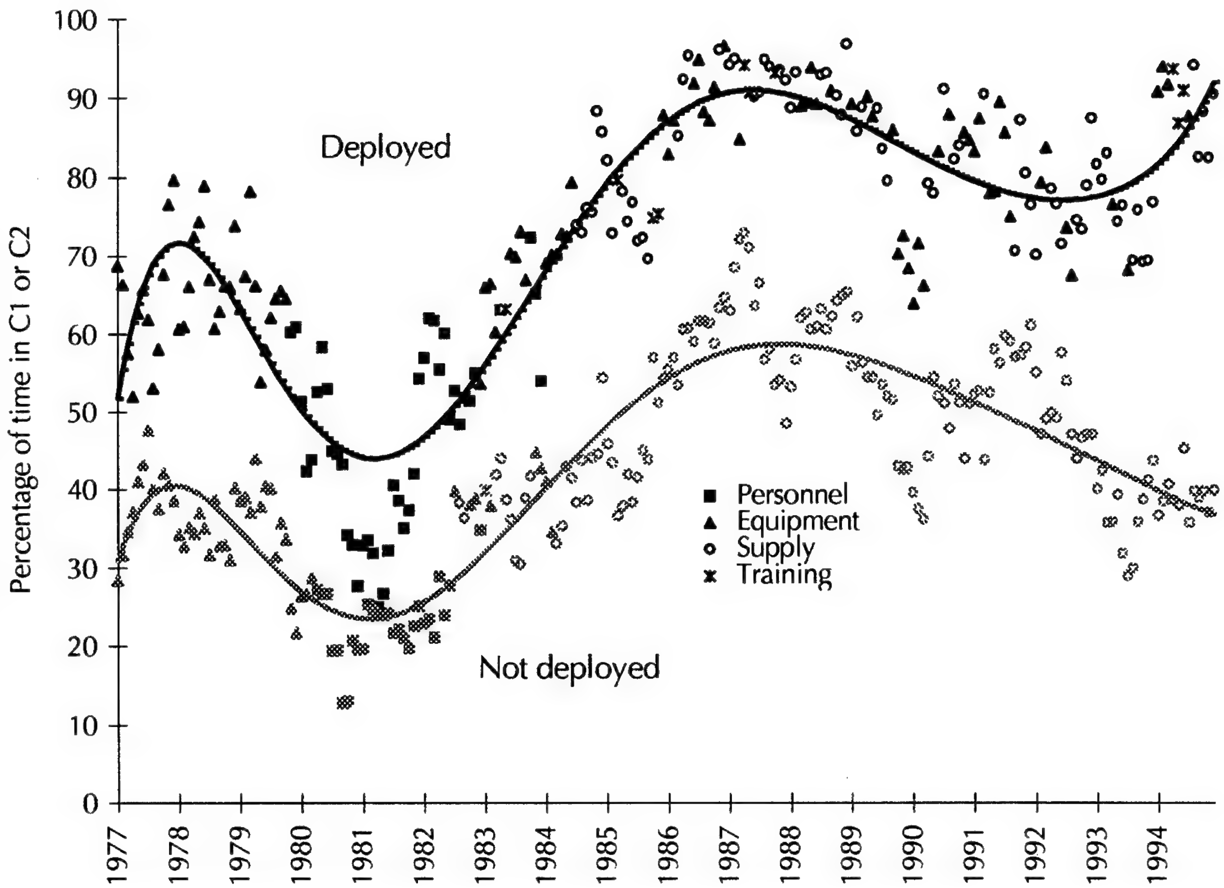
First, readiness generally moves in long, slow cycles characterized by an upward trend in the deployed units. Short-term movements of the data are not always meaningful. It is important to distinguish between these fluctuations and the movement of the general trendlines. The trendlines form a much better basis for action than do the short-term movements. The shape the trend takes is also important. Taken as a whole, these trends suggests that, based on SORTS data, the Navy's deployed units are much better off today than they were 10 years ago.

Periods of lower readiness

Second, there appear to be three periods of lower readiness. One occurred just before 1977. The second, which occurred in the early 1980s, was mainly the result of personnel shortages. This seems consistent with our review of past hollow periods, which highlighted the many problems the Navy had in the early 1980s matching senior petty officers to ship billets. The third, a modest decline occurring in the early 1990s, was the result of supply and equipment problems.

5. We compared the percentage of time the average surface combatant spent in C1 or C2 for all four resource categories for every month from the beginning of our dataset to the end. We then plotted the lowest of these on the graph in figure 2. This is what determined the shape the symbols would take.

Figure 2. Percentage of time surface combatants spend in C1 or C2, 1977–1994



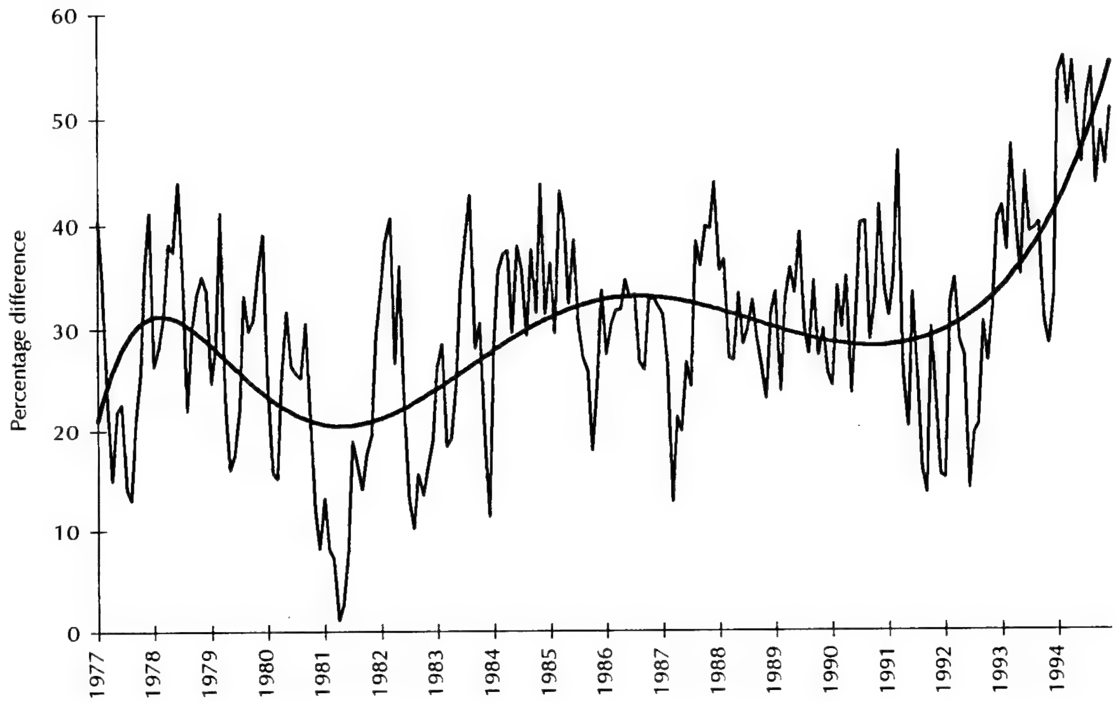
Lengthy trendlines should give senior leaders confidence that hollowness is not eminent. They allow analysts to identify peaks and valleys, which are useful in establishing benchmarks of times we want to return to and those we want to avoid. The distance we are away from these benchmarks should give us a degree of confidence about current status.

Deployed/nondeployed split

Third, there appears to be a relationship between deployed and nondeployed ships over time. The two have tended to move together, even during the decline in the early 1980s. This relationship, however, has begun to change. Today, the difference between deployed

and nondeployed surface combatants, which has increased gradually over time, appears to be rising sharply. Figure 3 depicts this change.

Figure 3. Percentage difference between deployed and nondeployed SORTS scores for surface combatants, 1977–1994

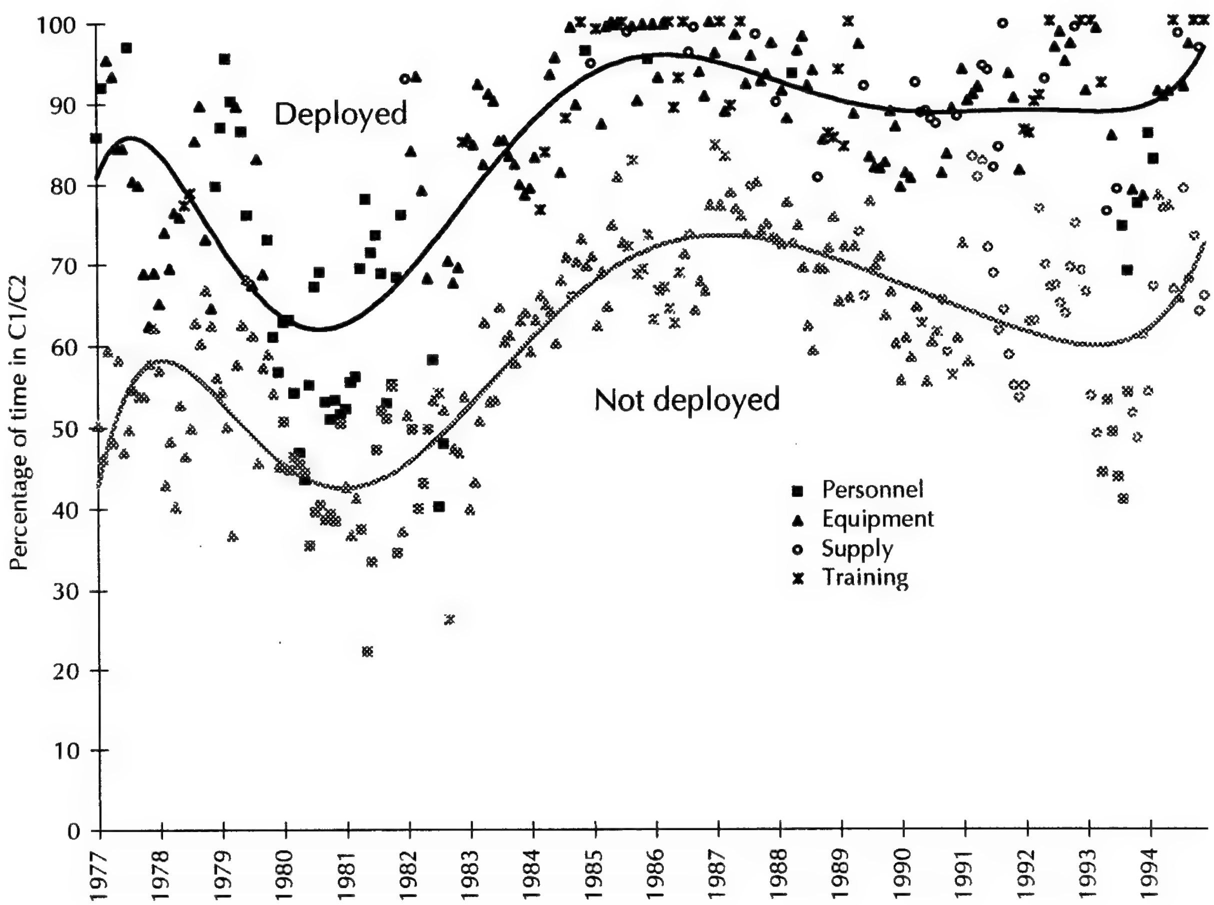


What is driving this split? One explanation is that nondeployed surface combatants are spending less time at sea getting ready for upcoming deployments than they did in the past. Another is that resources are being taken from nondeployed ships and given to deployed ships. Both explanations have the same effect and may be part of the same underlying problem, i.e., they are both driving down the percentage of time nondeployed surface combatants spend in C1/C2. Neither, however, necessarily explains what is causing this split.

When we looked at other classes of ships, this divergence between deployed and nondeployed ships was not always present. With regard to amphibious ships—as shown in figure 4—nondeployed readiness

appears to be rising in parallel with deployed readiness. This may reflect the strain of using a decreasing force of active-duty amphibious ships to meet a steady stream of operational commitments. Such a problem might suggest the need to deploy nondeployed ships in a way that allows them to fill the void left by smaller numbers of active-duty amphibious ships. In places like the Caribbean, this may not be difficult because a ship can easily make a round trip there without breaking the 56-day deployment rule.

Figure 4. Percentage of time amphibious ships spend in C1 or C2, 1977–1994

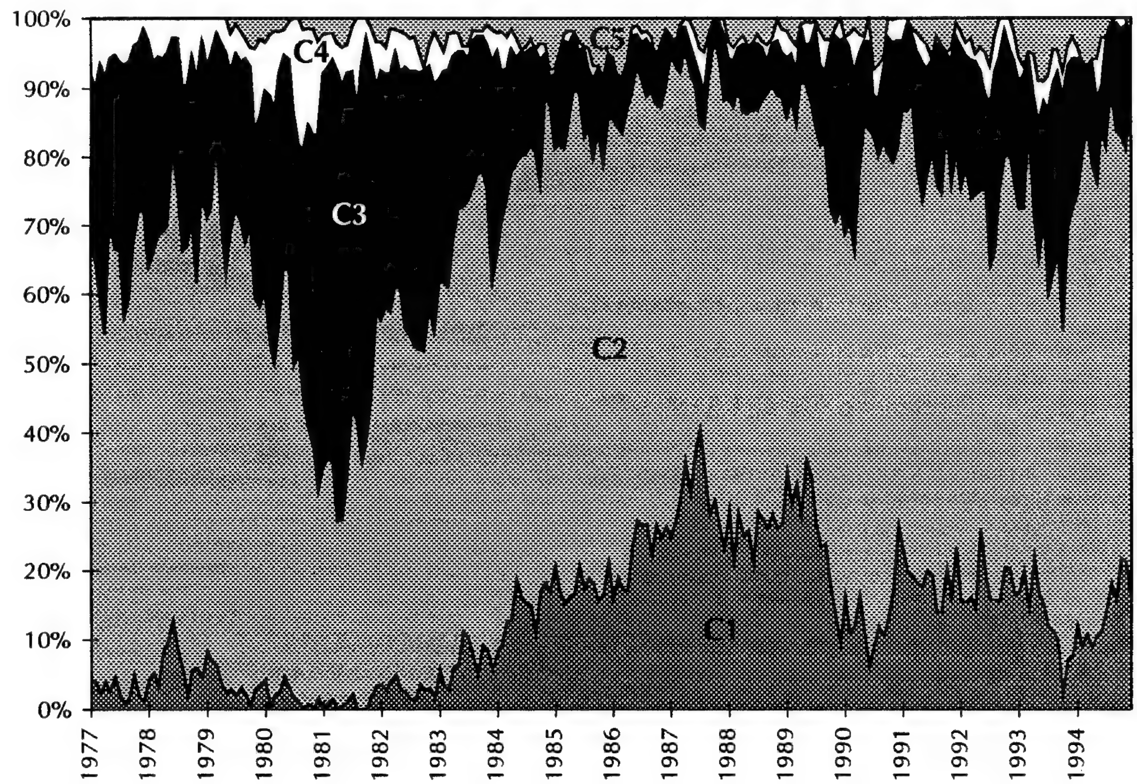


Still, there remains the nagging question of why surface combatant readiness is diverging between deployed and nondeployed ships. We first began to answer this question by looking at the historical distribution of C-levels for both deployed and nondeployed surface combatants. Figures 5 and 6 show this information. The graphs in both figures are punctuated by rather sharp cycles, which tell basically the same story as figure 2—readiness today looks a lot different than it did in the early 1980s. They also highlight the effect the Navy's overhaul cycle has in terms of the total number of ships in C1/C2 status--as they tend to rise and fall depending on the number of ships scheduled for maintenance in a given year. (C5 is reserved for ships undergoing some type of overhaul.) The effect seems most dramatic on the deployed side where over half of all surface combatants spend most of their time in C1 or C2 in a given year. The figure, however, does not shed much light on why deployed-nondeployed surface combatant readiness is diverging.

We next began to look at the resource categories contained within SORTS. Our original SORTS graph—figure 2—shows the resource categories that drag surface combatant readiness down. It shows that supply and equipment appear to be the weak links in ship readiness over the last 10 years. These two resource areas tend to be lower than the other two resource categories. They thus drive the overall SORTS score. Supply problems, in particular, seem most prevalent during a ship's nondeployed cycle.

In order to gain greater insight into this phenomenon, we looked at the reason codes ships submit as part of their regular SORTS reports. SORTS requires that each ship reporting C2 or below for any resource category must submit a reason code explaining the rating they are reporting. Examples of the types of deficiencies that are given for why a ship may not be C1 include inoperative weapons, ammunition shortages, a high failure rate for certain critical parts, missing personnel, failed operational evaluations, and cancelled training evolutions. Reason codes help identify the constraining factors that limit a ship from achieving its full wartime potential. Our analysis focused on what these reason codes might tell us about the growing split between deployed and nondeployed ship readiness as measured by SORTS.

Figure 5. SORTS distribution for deployed surface combatants, 1977–1994[a]

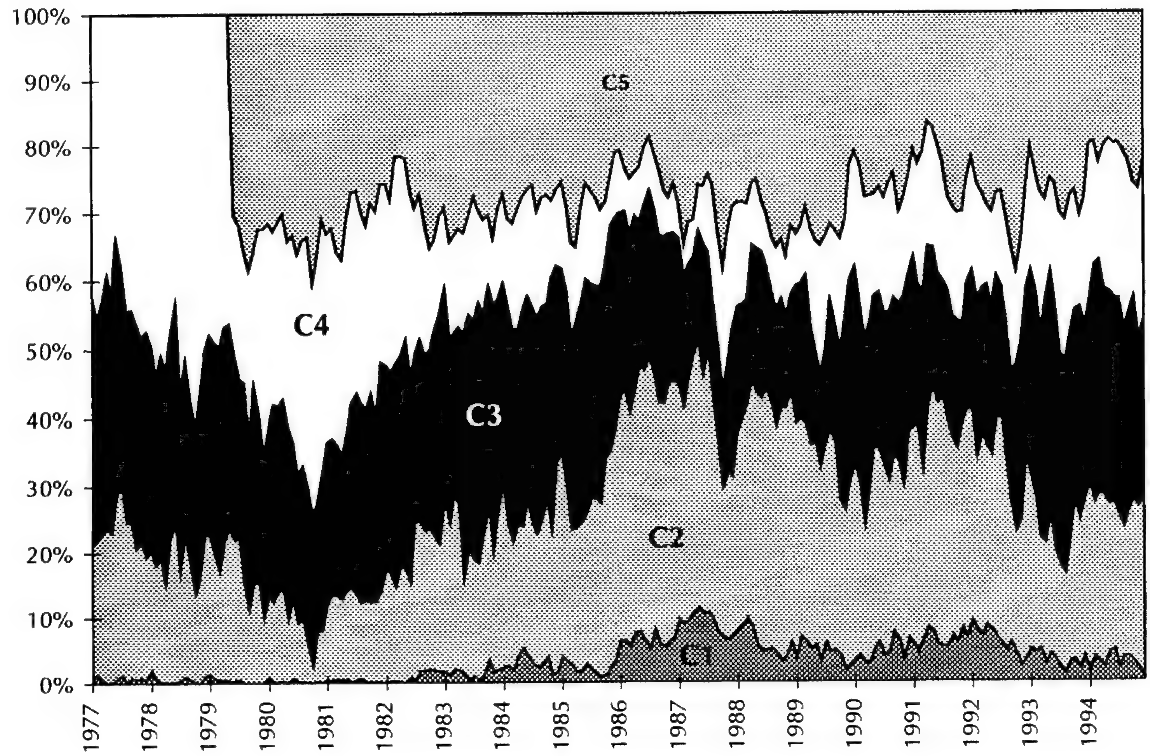


a. CNA's ship employment history database shows only four readiness levels a ship could be in at any one time between 1977 and 1979.

Since figure 2 identifies supply deficiencies as the principal reason nondeployed surface combatant readiness is lower than deployed surface combatant readiness, we thought it would be interesting to look at supply-related reason codes. In figure 7, we list the reasons surface combatants give for not being C1 for supply for each day from 1977 through 1994. The graph shows that ammunition-related deficiencies tend to cause a ship to report at less than a C1 level for supply much more so than other deficiencies. What's more, it appears that whenever ammunition is a problem, it almost always involves a shortage of one sort or another. These shortages have several causes. They include those that arise due to:

- Missing component parts

Figure 6. SORTS distribution for nondeployed surface combatants, 1977–1994[a]



a. See note for figure 5.

- Heavy usage
- Delays in reordering
- Small numbers of operating targets
- Programming shortfalls
- Tailored loads
- Allowance lists being less than the wartime mission demands.

Figure 8 goes one step further. It breaks ammunition-related deficiencies into several categories (bombs, guns, mines, missiles, etc.) and crosstabulates these with the specific deficiency found to exist on a given day on the average ship. What we see is that missile shortages are the driving factor affecting a ship's ability to be C1 for supply. A

secondary concern are shortages of guns and torpedoes. Rocket shortfalls are a distant fourth. Only maintenance-related missile deficiencies come anywhere close to being as common a problem for Navy supply readiness as ammunition shortages.

Figure 7. SORTS reason codes explain equipment- and supply-related deficiencies on Navy surface combatants, 1977–1994

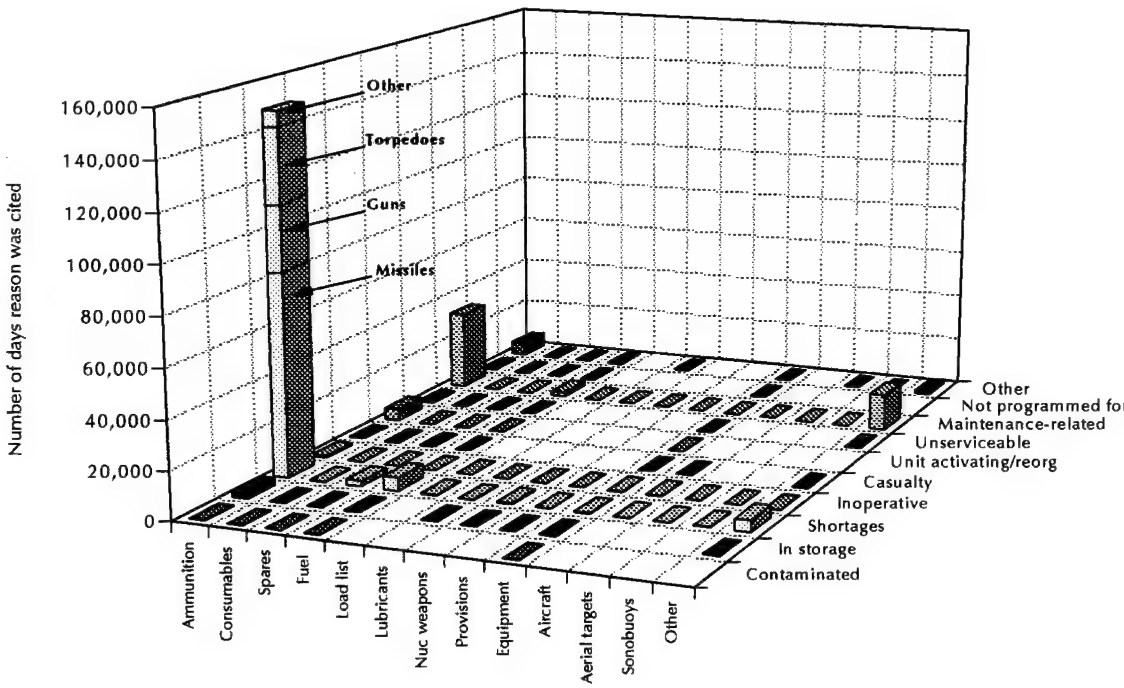
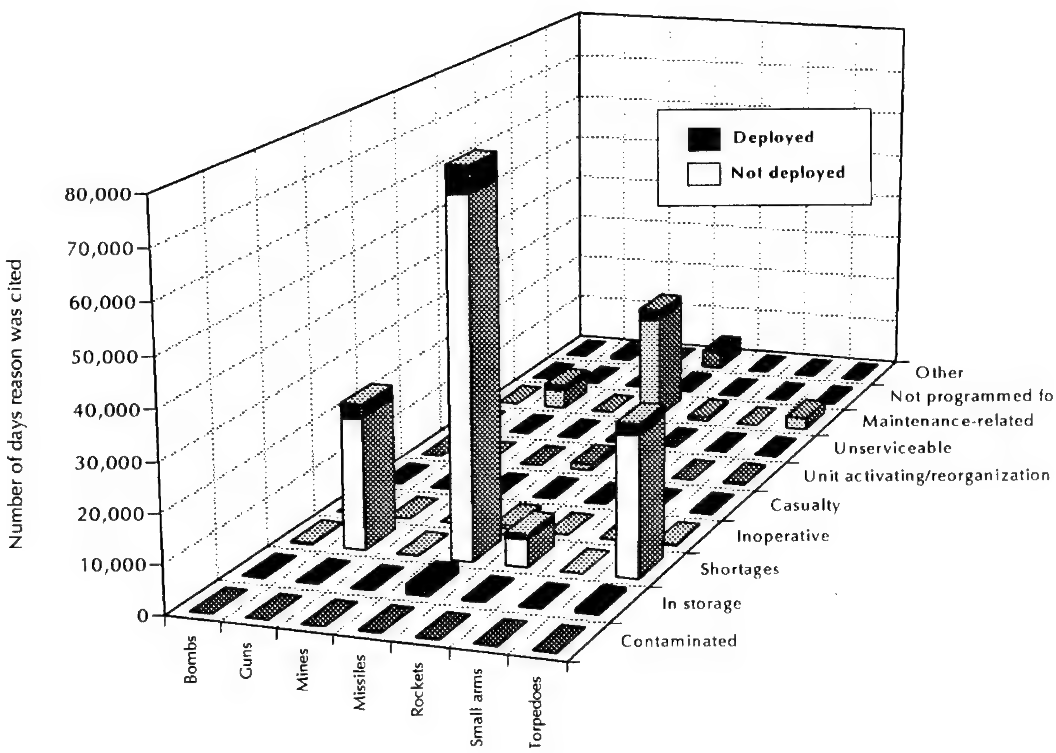


Figure 8 also highlights when these problems are likely to arise: Do they occur when a ship is deployed or during the time it is not deployed? As figure 8 depicts, almost every time an ammunition shortage prevents a ship from being C1, it occurs during the nondeployed period. What this suggests is that ammunition is often recycled from ships that recently return from overseas to ships that are about to deploy. The danger to this practice is that should it be necessary to surge a great number of ships to a theater of war, some ships will be missing invaluable ordnance. It also runs the risk of preventing crew

Figure 8. SORTS reason codes explain ammunition-related deficiencies on Navy surface combatants, 1977–1994



members assigned to nondeployed ships from training with the materiel they will use in war. Of course, this is manageable depending on when ammunition arrives onboard.

On the other hand, it may not make a lot of sense to add more missiles and other ordnance to the system only to improve nondeployed ship readiness, as it would have little effect on U.S. forward presence capabilities. It also would be a mistake to change the requirements against which nondeployed surface combatants report supply readiness. Even though chronic shortages appear the rule rather than the exception, changing reporting requirements would do little but artificially raise readiness reporting levels. It would not alter nondeployed capabilities—only a large buy of ammunition would do that. One negative effect of a change in reporting requirements would be

to distort the existing historical baseline, making it much harder to spot similar trends, such as the split between nondeployed and deployed ship readiness in the future.

The impact of training

Finally, figure 2—our picture of SORTS trends for Navy surface combatants—highlights how seldom training affects Navy readiness as measured by SORTS. It rarely if ever drags overall SORTS scores down. Intuitively, this makes sense. Training is often viewed as the most gameable SORTS category because it is so dependent on the unit commander's subjective assessment of training accomplishment. This perception was clearly evident in our survey. But note in figure 2 that when training appears to be dragging the amount of time the average surface combatant spends in C1/C2, it does so only during times of strong readiness on the deployed side and never on the nondeployed side. Figures 3 and 9—which show overall SORTS trends for amphibious ships and submarines—depict a similar pattern. Basically, we can infer from this that when training readiness is the lowest resource category, overall readiness is exceptionally high.

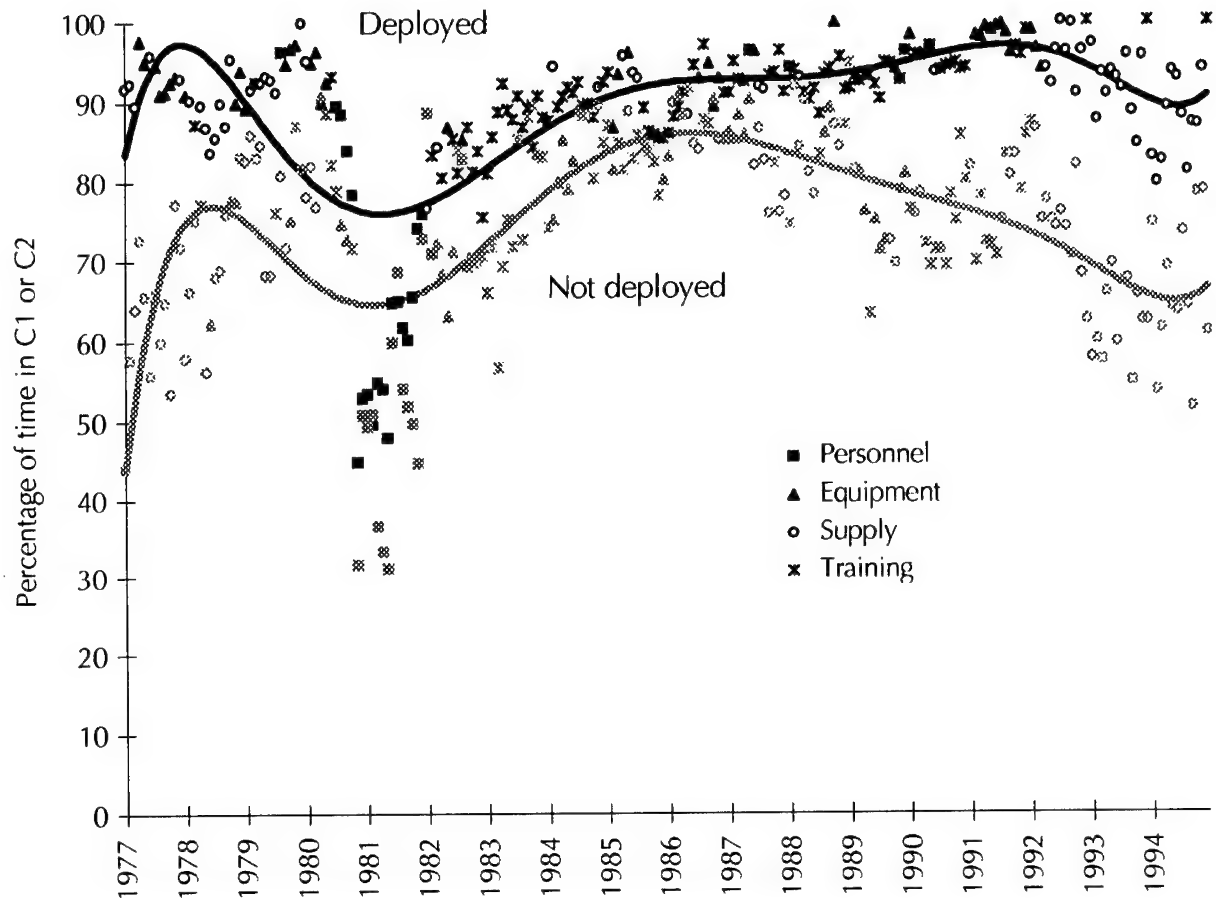
This is not necessarily the case for aircraft. Figure 10, which shows the percentage of time fighter and fighter-attack aircraft spend in C1/C2, tells a different story. It shows training resources as the weakest link in SORTS, i.e., the one that drives overall SORTS down. This suggests what past research has shown—that flying time is indeed strongly correlated with readiness [6, 7].

Material condition

Readiness within the Navy is often equated with the material condition of ships and aircraft. This is not surprising because the Navy is a capital intensive force. Many analysts use the absence of serious casualties (CASREPs) for ships and mission capability (MC) rates for aircraft to measure material condition.

We looked closely at the number of CASREPs that occurred on board Navy ships between 1977 and 1994. Figure 11 shows the data. The historical evidence shows that the percentage of time free (POTF) of C3/C4 CASREPs increased from 1975 to 1978 on a Navy-wide basis and then declined slowly, with a dramatic drop in 1981, the same year the bottom dropped out from under overall SORTS scores. The trend is

Figure 9. Percentage of time submarines spend in C1 or C2, 1977–1994

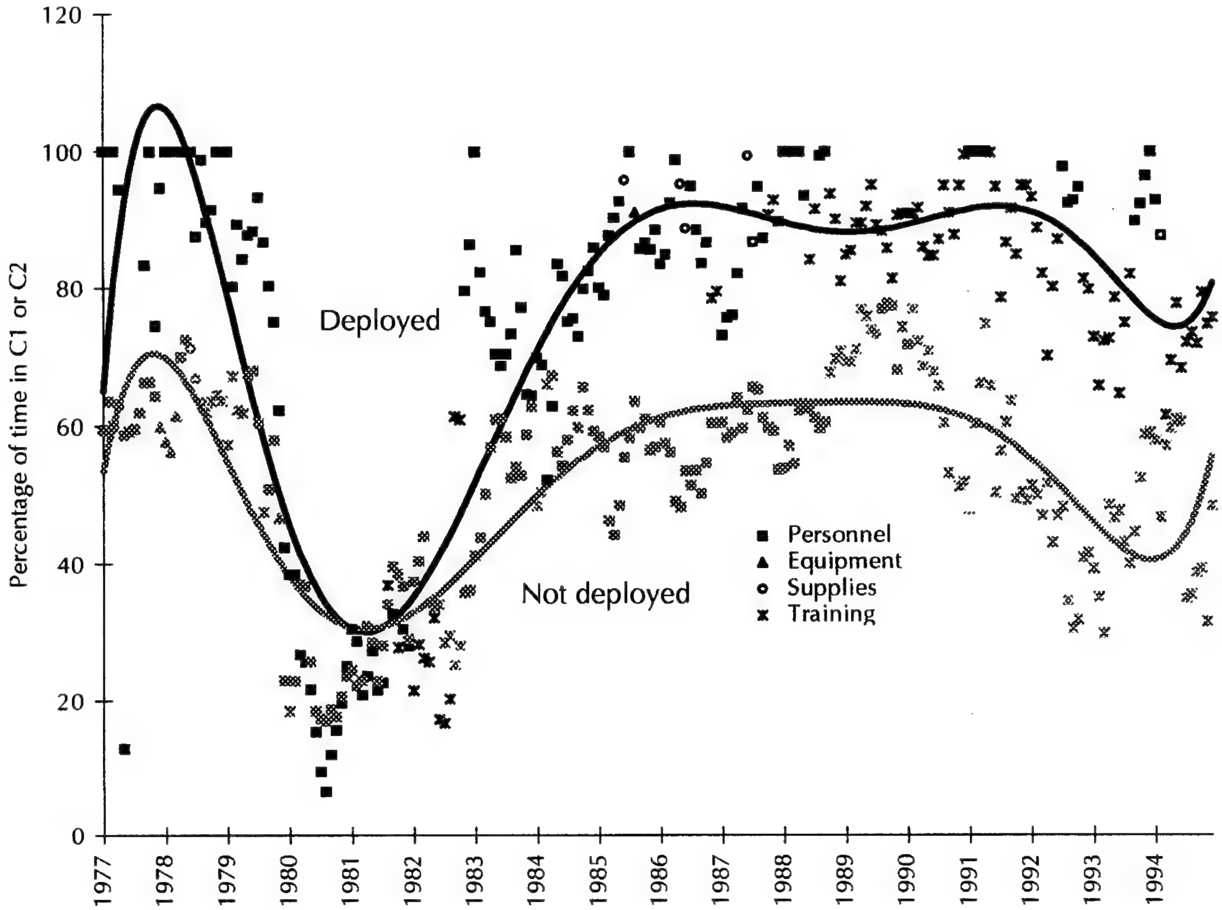


the same for all types of surface ships—combatants, amphibious ships, and auxiliaries. Submarines, which typically receive resource priority, hardly ever see a C3/C4 CASREP. Their material condition seems unaffected by general Navy readiness trends. One could argue that the Navy submarine force was never hollow.

Limitations

The commanding officer (CO) of a ship files a CASREP whenever the failure of a piece of equipment results in the loss of significant capability. Within the Navy, a CASREP is largely viewed as a signal for assistance, i.e., it signals that a ship needs the logistics pipeline to find and quickly supply it with a critical spare part or equipment component.

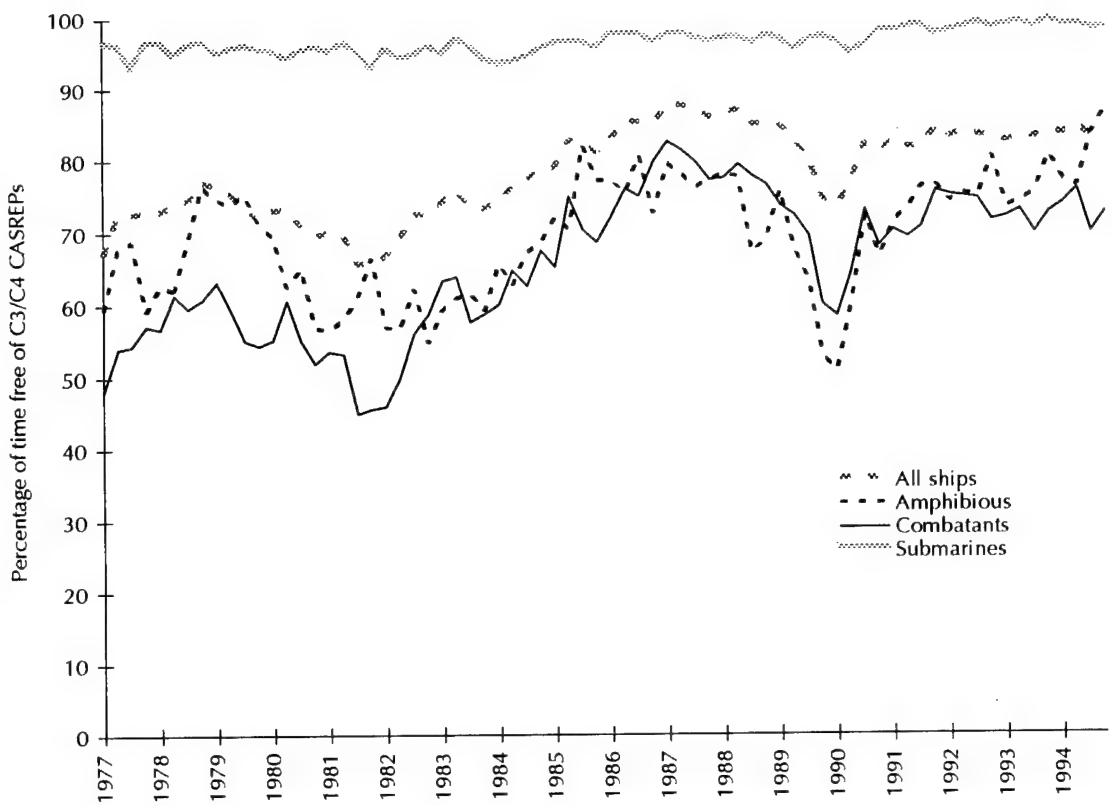
Figure 10. Percentage of time fighter and fighter-attack aircraft spend in C1 or C2, 1977–1994



But it may also be a commentary on the CO who is thought to exercise a good deal of discretion in filing CASREPs.

Past research on CASREP data at the individual ship level suggests that CASREPs tend to occur more often just after a ship completes an overhaul cycle, and then steadily decline for about a year [8]. There is little evidence to suggest that the number of CASREPs surface combatants experience is a major problem for ships that have not had any depot maintenance for an extended period—at least out to 24 months [9].

Figure 11. Percent of operating time free of CASREPs (C3/C4) for select classes of deployed Navy ships



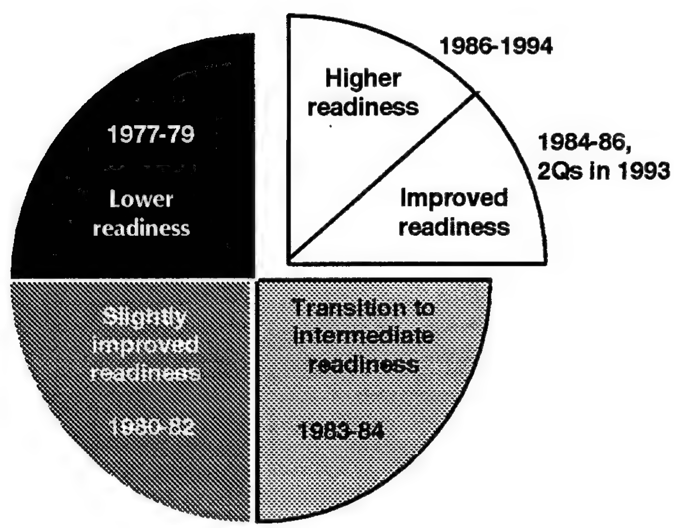
Clustering

Because CASREP data is long and continuous, and it is used at least as often as SORTS in measuring Navy readiness, we decided to examine the two together to see if they tell the same story. We performed a statistical technique on this data known as cluster analysis, which helps us group similar data. Basically, it groups periods that are similar to one another in terms of readiness characteristics.

We performed cluster analysis on 18 indicators of Navy surface combatant readiness [10]. Our data included various SORTS resource categories and CASREP data representing the readiness levels achieved by both deployed and nondeployed surface combatants over an

18-year period. The analysis shows a major split between readiness data from 1977 to 1984 and data from 1984 to 1994. The split between these two periods was big—in total, it explains about 70 percent of the variation. Another 11 percent is explained by further breaking down the years 1977 through 1984 into the three groups shown in figure 12. Only 3 percent of the variation is explained by breaking up the more recent years into two separate clusters.

Figure 12. Graphical representation of the clusters associated with SORTS and CASREP data from 1977–1994

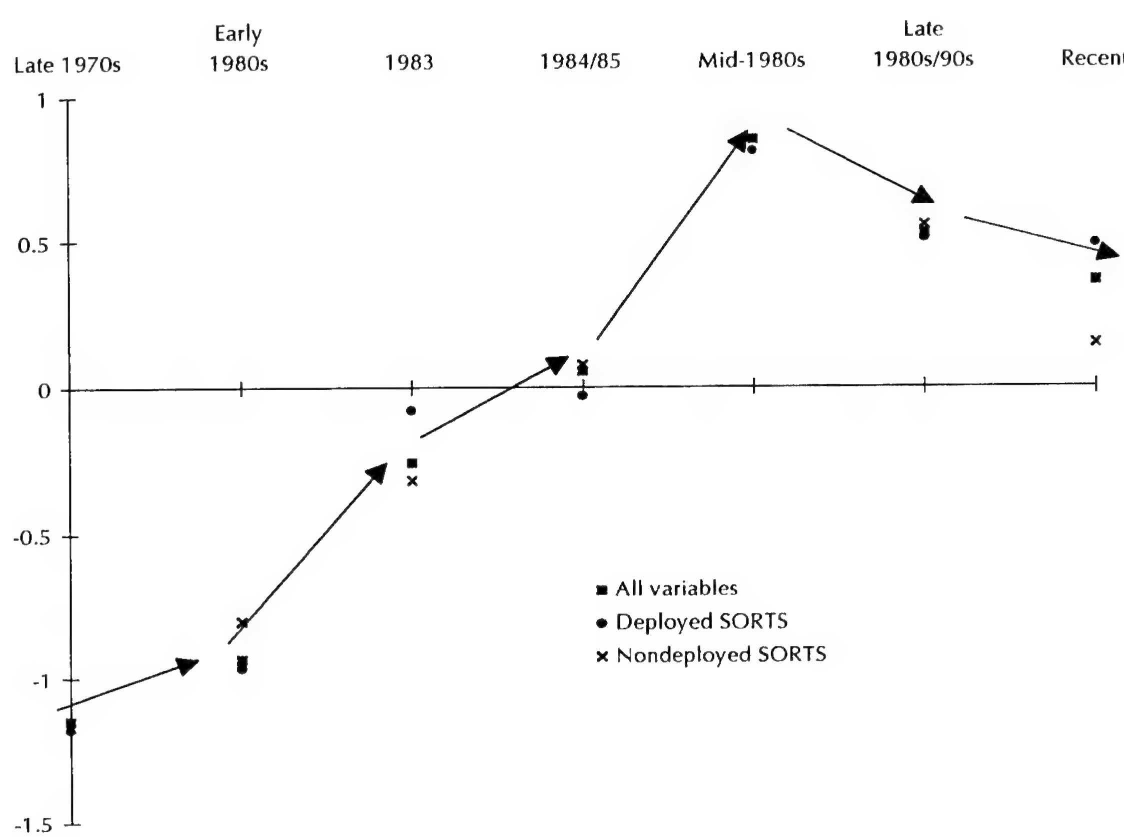


Using the cluster data as our baseline, we treated the movement from the center of one cluster to the center of another as a vector. To calculate the center of each cluster, we used the average of all the indicators that comprise the data within the cluster. After standardizing all the averaged data, we can draw vectors between the averaged centers of each cluster. The vectors formed are depicted in figure 13. This figure shows the general direction in which readiness has moved

since the late 1970s. The distance separating the various cluster centers helps us understand:

- The general direction in which readiness has moved
- The speed with which it has moved (if one equates distance to speed).

Figure 13. Readiness vectors



By adding other variables not covered in this analysis (such as personnel quality), we can get a better sense of the speed and general direction that readiness has taken. (See appendix C.)

All this reinforces the notion that readiness is a slow-moving process. It takes time to pull out of hollowness, just as it takes time to fall into

it. What's more, there appear to be—as our historical analysis suggests and our original SORTS graphs supports—distinct periods of higher and lower readiness. Again, these periods offer benchmarks that can help us avoid hollowness. If incoming data clusters with periods of lower readiness, it signals to senior leaders that readiness problems are afoot. If, on the other hand, the data groups with periods of higher readiness, then it should reassure senior leaders that all is well in terms of overall Navy readiness.

Factors associated with readiness

SORTS and CASREPs are commonly used to measure readiness, but other factors have an effect as well. These factors include the quality of personnel, manning, OPTEMPO (as a proxy for training), and spares availability.

Quality of personnel

Most people agree that quality personnel have a positive impact on readiness, but the exact relationship is not clear. SORTS contains little information about the quality of personnel serving in a unit—other than whether enough people are present. In short, it describes whether the Navy has successfully matched faces to existing spaces.

Personnel quality has many dimensions that a readiness analyst might wish to track. These include capacity, training, and experience. Capacity refers to the raw material the military has to work with in bringing new accessions into the service, and includes such characteristics as intelligence and personality. Training includes formal schoolhouse instruction and on-the-job learning. Experience refers to the improved productivity gained through years of service [11].

Because it is multifaceted, we thought an index of personnel quality, with relevant variables properly weighted, might give us insight into how personnel quality has changed over time. Therefore, we began by collecting 17 years of quarterly data on the crews of surface combatants. This data included:

- The percentage of crew members with a high school degree (HSDG)—a proxy for motivation.

- The percentage of crew members testing in the highest mental (I, II, and IIIA) on the Armed Forces Qualification Test (AFQT)—a proxy for aptitude.
- The percentage of crew members demoted, as measured by the percentage of crew who moved to a lower pay grade—a proxy for discipline problems.
- The average length of service (LOS) for crew members—a proxy for experience.
- The frequency of rapid advancement, as measured by the percentage of E5s and above with less than 4 years of service—a proxy for the effect that personnel shortages have on the Navy as a whole. This phenomenon can cause many sailors—more than one would expect—to advance rapidly up the promotion pyramid. At a force-wide level, too much of this is not a good thing.

Figures 14 through 18 show how each of these variables have behaved over time. Note that the shape of figure 15, which depicts the percentage change in the number of crew members testing in the top two categories of the AFQT, looks remarkably similar to that of figure 2—which shows our original SORTS graph for surface combatants—when it's not flattened out by the high percentage of crew members on submarines testing in the top three categories. This is good to find in a readiness indicator—something that tells a familiar story.

All the trendlines in figures 14 through 18 tell similar stories—personnel quality appears to be moving in the right direction. But that message can be distorted or even lost when there is too much data, one can get caught up in meaningless, short-term fluctuations in one data set and ignore the overall trend. Figure 19 shows what the data depicted in figures 14 through 18 look like when standardized—where each one has a mean of zero and a standard deviation of one. It is still extremely difficult to summarize the overall trend. Indeed, there is nothing intuitive about this chart—despite the fact that each trendline is going in the direction we want it to go.

Figure 14. Percentage of crew members on Navy surface combatants with a high school degree, 1977–1994

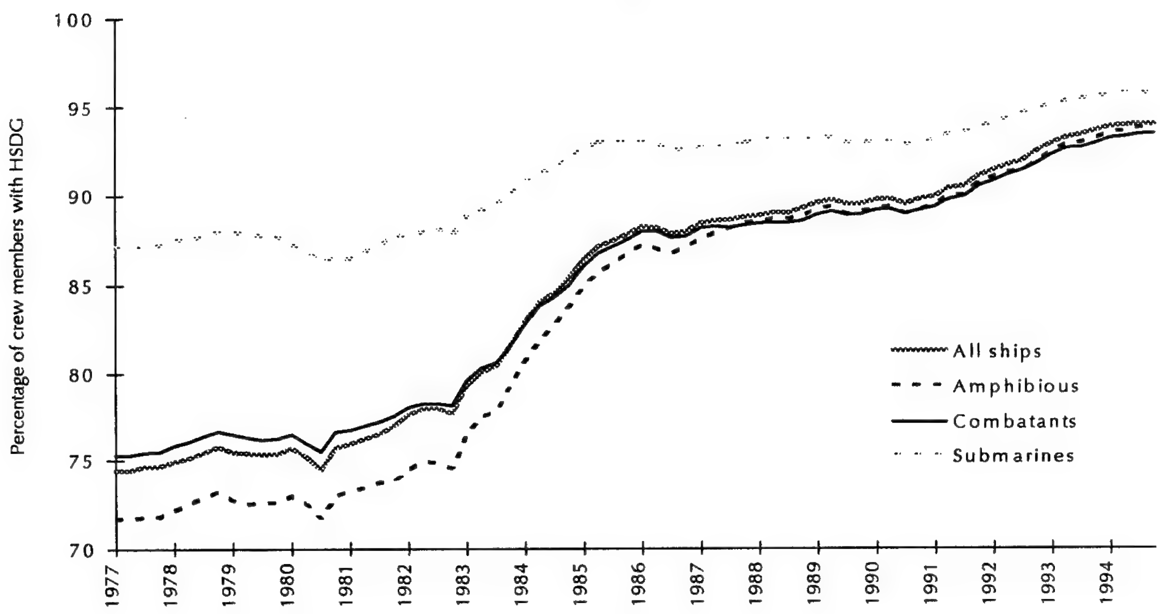


Figure 15. Percentage of crew members on Navy surface combatants in the upper mental group, 1977–1994

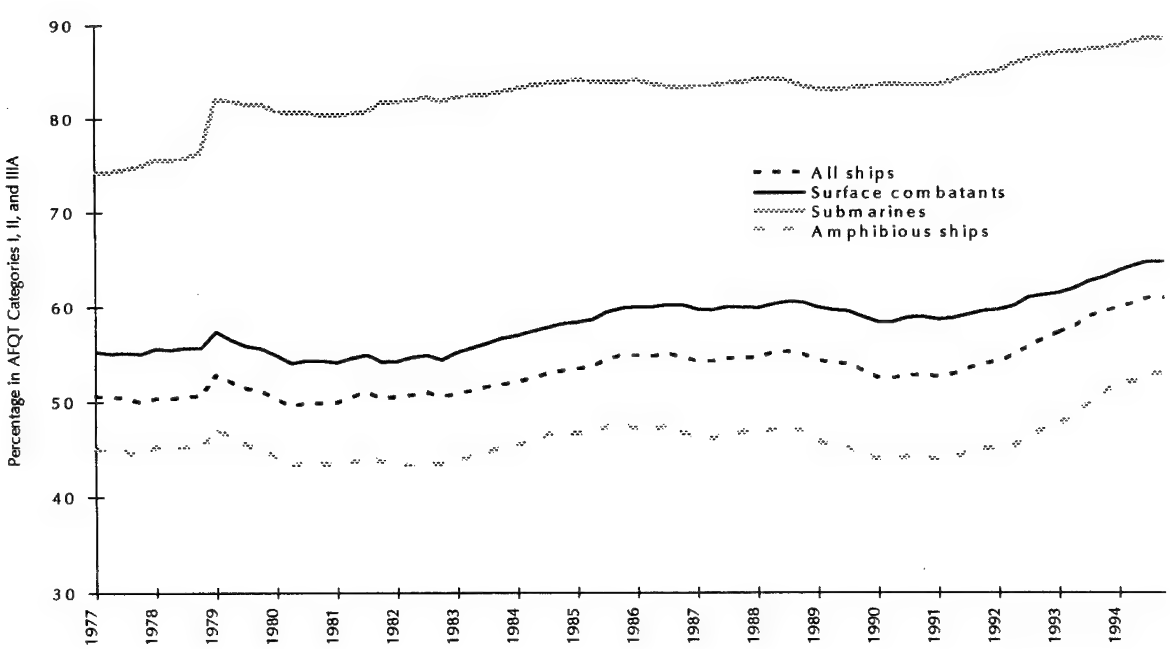


Figure 16. Average length of service of crew members on Navy surface combatants, 1977–1994

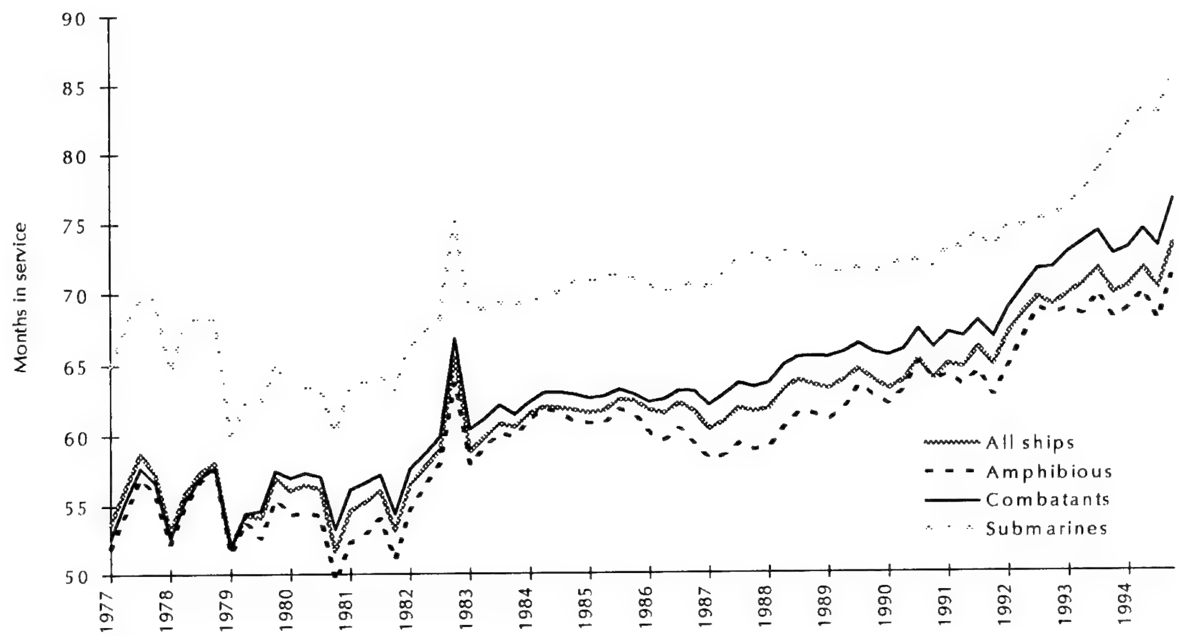


Figure 17. Percentage of crew members on Navy surface combatants who were demoted, 1977–1994

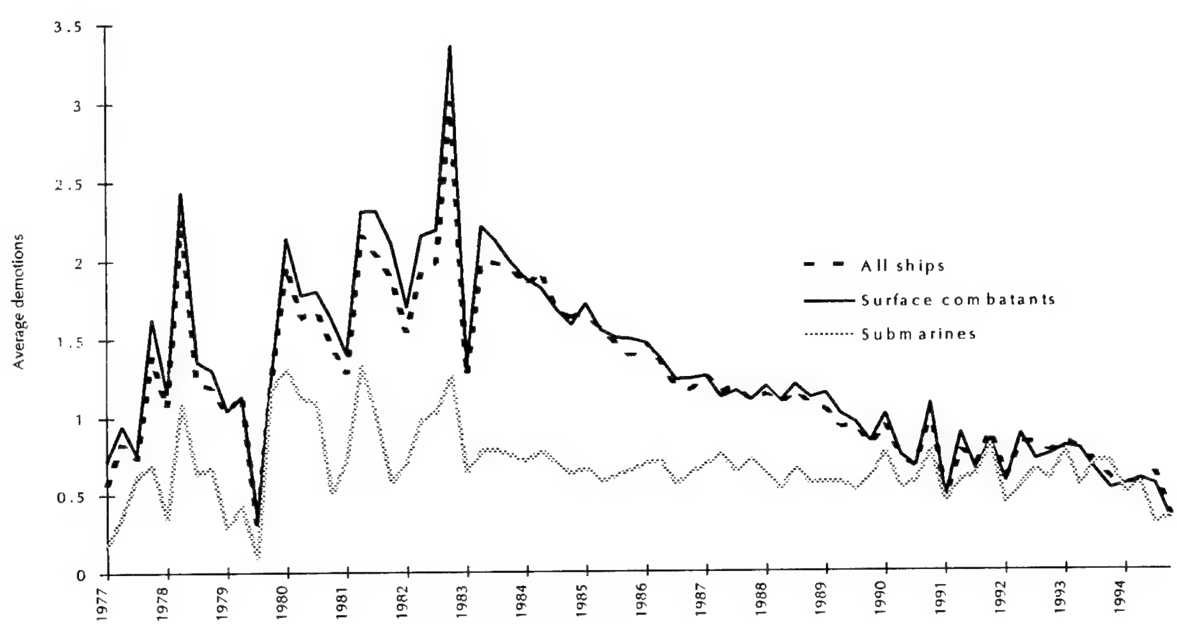
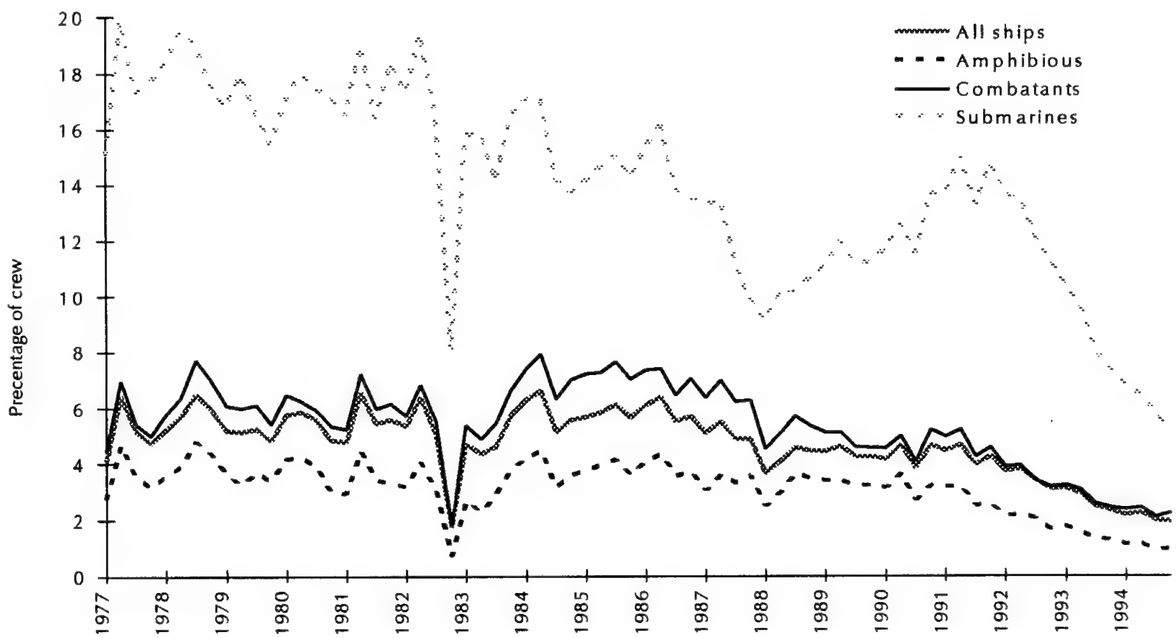


Figure 18. Percentage of E5s and above on Navy surface combatants with less then 4 years of experience, 1977–1994



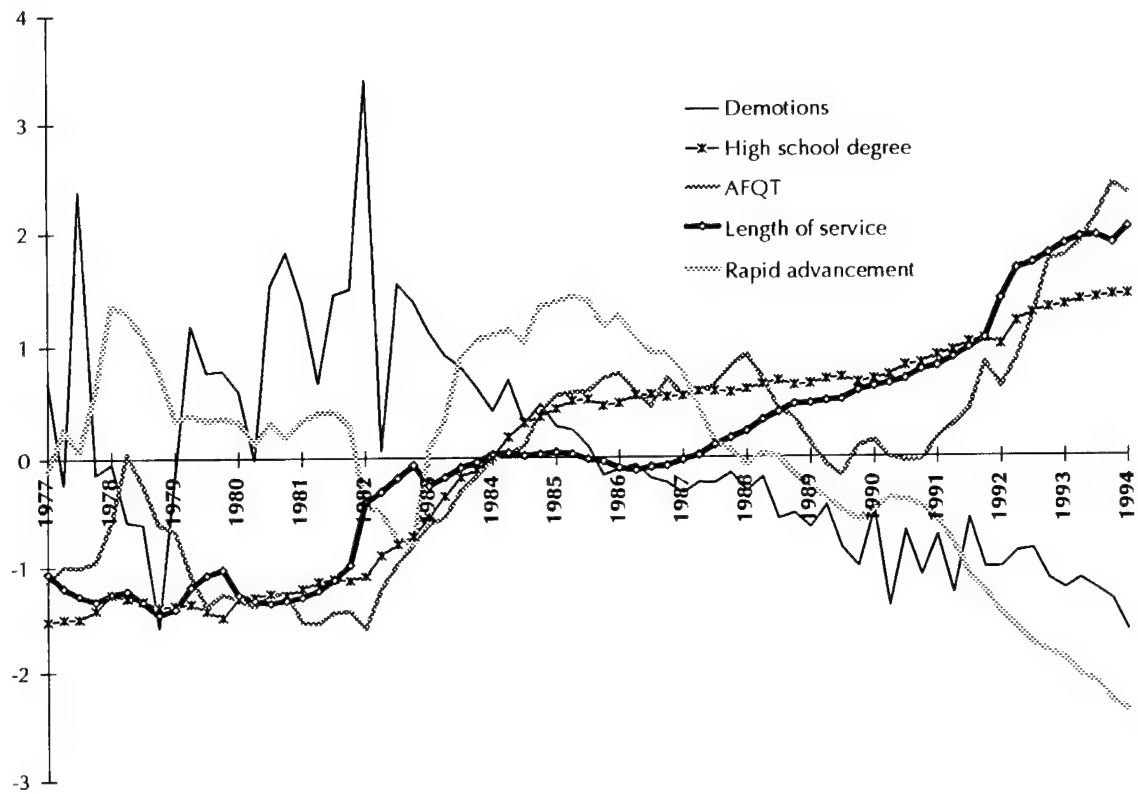
Principal components

We applied a method called principal component analysis to help us determine what all these detailed indicators are trying to tell us [12]. Principal component analysis selects weights for each variable based on variations within the entire dataset. Principal components help describe variations within the data. The analysis will generate as many principal components as necessary to explain all the variance within a certain dataset.[6]

This technique is generally used to discover patterns among the variations in several variables. Here it helps us assign weights to a select group of indicators of personnel quality, and interpret those hidden or unobservable indicators that generate variation within a set of indicators. This is done by generating artificial dimensions (principal

6. Documentation provided in CNA Annotated Briefing 95-9, *Analyzing Readiness Indicators*, by Laura J. Junor, May 1995.

Figure 19. Average personnel quality for Navy surface combatants, 1977–1994



components) that correlate highly with observable variables (such as AFQT scores, length of service, rapid advancement, etc.). In our analysis, the first principal component that was generated explained much of the variance in all five personnel quality variables (74 percent). Table 3 summarizes the weighting scheme that the first principal component created.

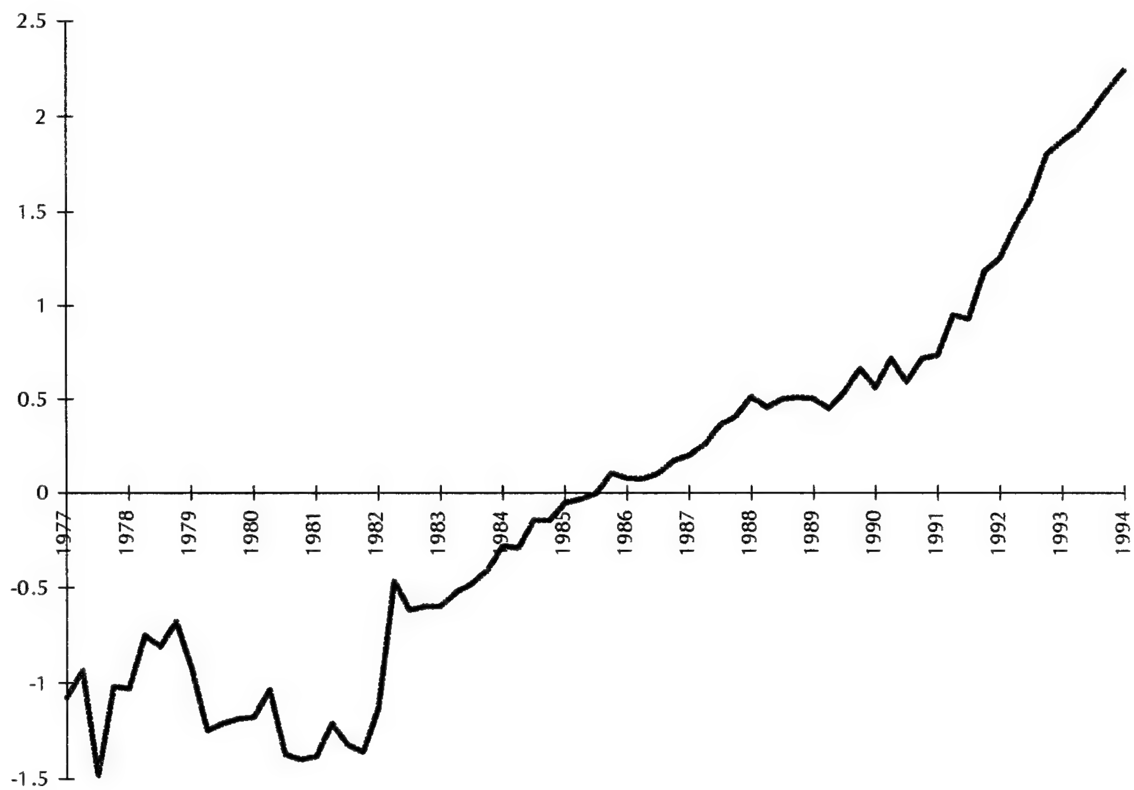
As the table indicates, the first four variables (HSDG, AFQT, demotions, and LOS) have almost equal weights. The frequency of rapid

Table 3. Summary of principal component weights

Variable	Weight
Percentage of crew with HSDG	.60
Percentage of crew that scored in Cats I & II of AFQT	.40
Percentage of crew that are demoted	-.45
Average length of service (LOS) for crew	.50
Frequency of rapid advancement	-.10

promotion has the lowest. The weights also indicate that demotions and lack of time in grade (frequency of rapid advancement) negatively influence crew quality. Figure 20 shows how these weighted

Figure 20. navy surface combatant personnel quality index 1977–1994



averages have changed over time. We have plotted this index to a mean of zero to compare the number of deviations we are now experiencing from the mean. In other words, what we care about is how we look today in relation to where we've been in the past. This figure shows that we are now more than two standard deviations above the average, which tells us that personnel quality is extremely high and has been so for some time.

Ship and squadron manning

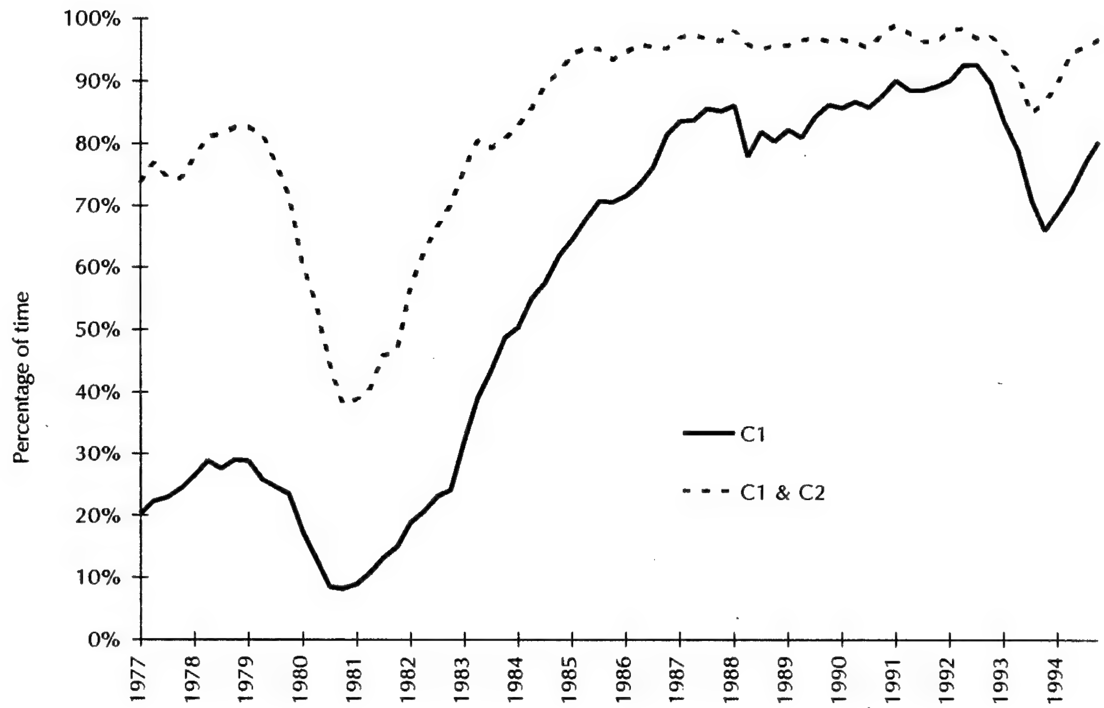
Just as personnel quality plays a big role in determining readiness status, so too does the number of sailors who are available to fill key billets. This, of course, means more than having enough numbers but also having trained personnel with the right mix of skills. Past studies have shown that ship manning is highly related to the percentage time free (POTF) of C3/C4 CASREPs and better performance in select mission exercises. One study found that a 10-percent decline in ship manning was correlated with a 38-percent reduction in POTF [13]. Another study found that a 10-percent increase in senior manning was related to a 5- to 10-percent increase in exercise scores [14].

Squadron manning has also been found to be highly correlated with aircraft MC rates. This relationship is on the order of a 3-percent reduction in MC rates for every 10-percent decline in senior manning—meaning E4 through E9s [15].

Most measures of personnel quantity involve some form of fill rate, i.e., manning level relative to M+1 requirements, the mix of personnel on-hand (in terms of available NECs and ratings), etc. One way to measure this is through the personnel subcategory of SORTS. As noted earlier, SORTS measures the number of people a unit has on-hand against requirements. Thus, it should serve as a good proxy for how ship manning levels have changed over time. This is what is highlighted in figure 21.

In the figure, it appears that the Navy had serious manning problems throughout the early 1980s, probably the result of a shortage of petty officers at that time. Since then, however, ship manning (as measured by personnel SORTS ratings) appears to be rather good with only a slight dip occurring between 1993 and 1994.

Figure 21. Personnel SORTS scores for Navy surface combatants, 1977–1994



OPTEMPO

The Navy has long been concerned about the impact operating tempo (OPTEMPO) has on the material readiness and training of Navy ships.[7] Most of those we spoke with in our survey were deeply concerned about this question. They felt that the Navy was in peak form, but they feared that current operating conditions were straining it beyond its means. They feared that an imbalance had been struck between the number of commitments the Navy was required to meet and the amount of resources available. In short, they feared that the fleet was increasingly busy at a time of decreasing size.

7. We use the term OPTEMPO to refer to the number of flying hours, vehicle miles, and steaming days expended per period. PERSTEMPO, on the other hand, refers to the amount of time units and their assigned personnel are away from home. See, for example, [25, 26].

One way to gauge how OPTEMPO is affecting the fleet is to look at how the Navy has been used in the past. There seem to be two basic concerns: (1) That the fleet is being asked to do more with less; and (2) that those who remain are working harder than ever to compensate for reduced numbers. Figure 22 puts the latter concern—that the Navy is increasingly busy today—into historical perspective.

Figure 22. Total number of ships deployed in select classes, 1977–1994

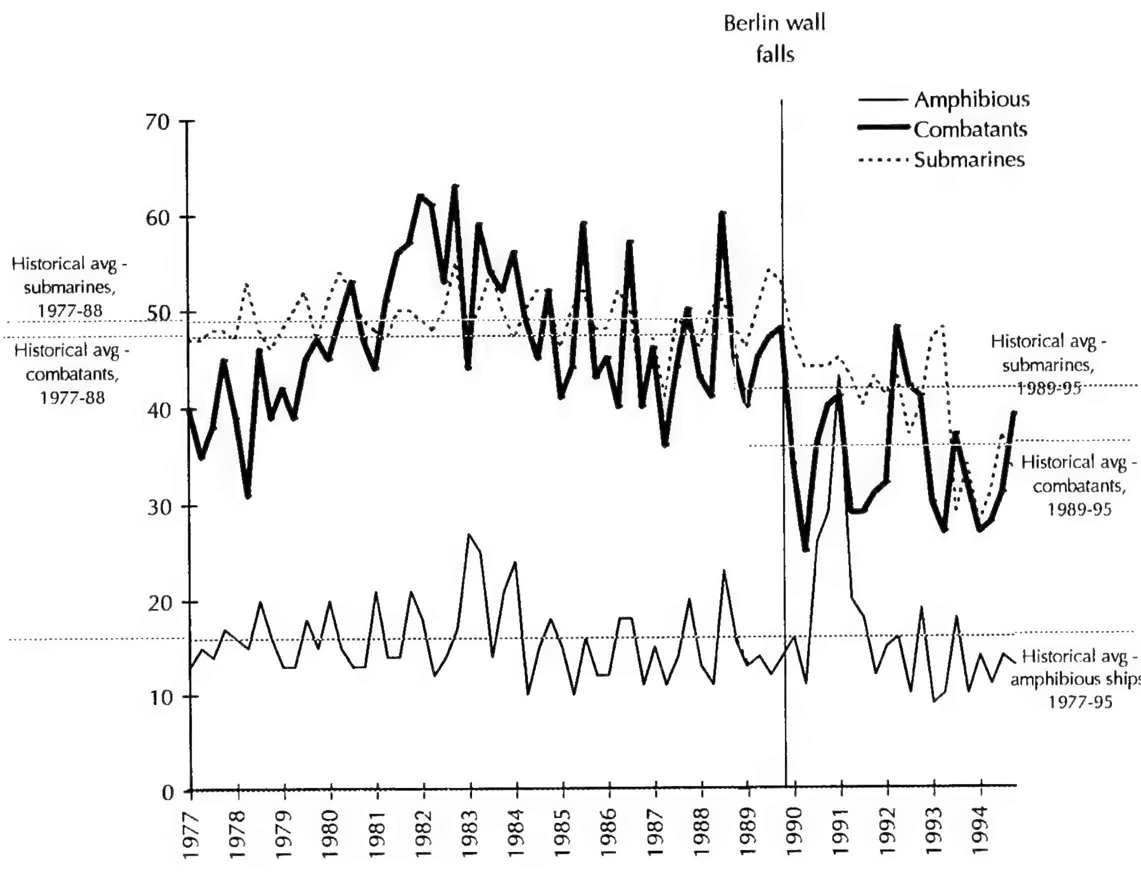
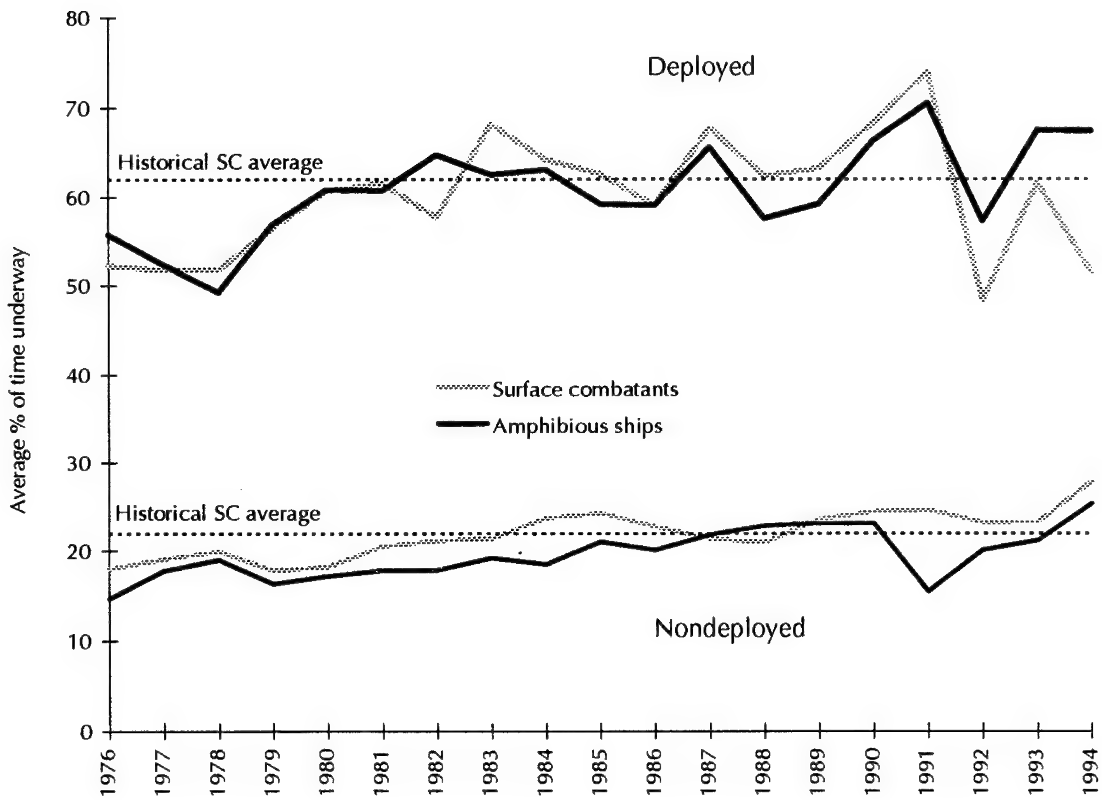


Figure 22 depicts the number of ships from select classes that spent 56 days or more away from home port in a given year. In other words, it shows the total number of ships that were deployed at a given time

Figure 23. Percent of time select ship classes spend underway, 1977–1994



over an 18-year period. It gives some indication about how forward presence requirements have shifted since the Cold War ended.

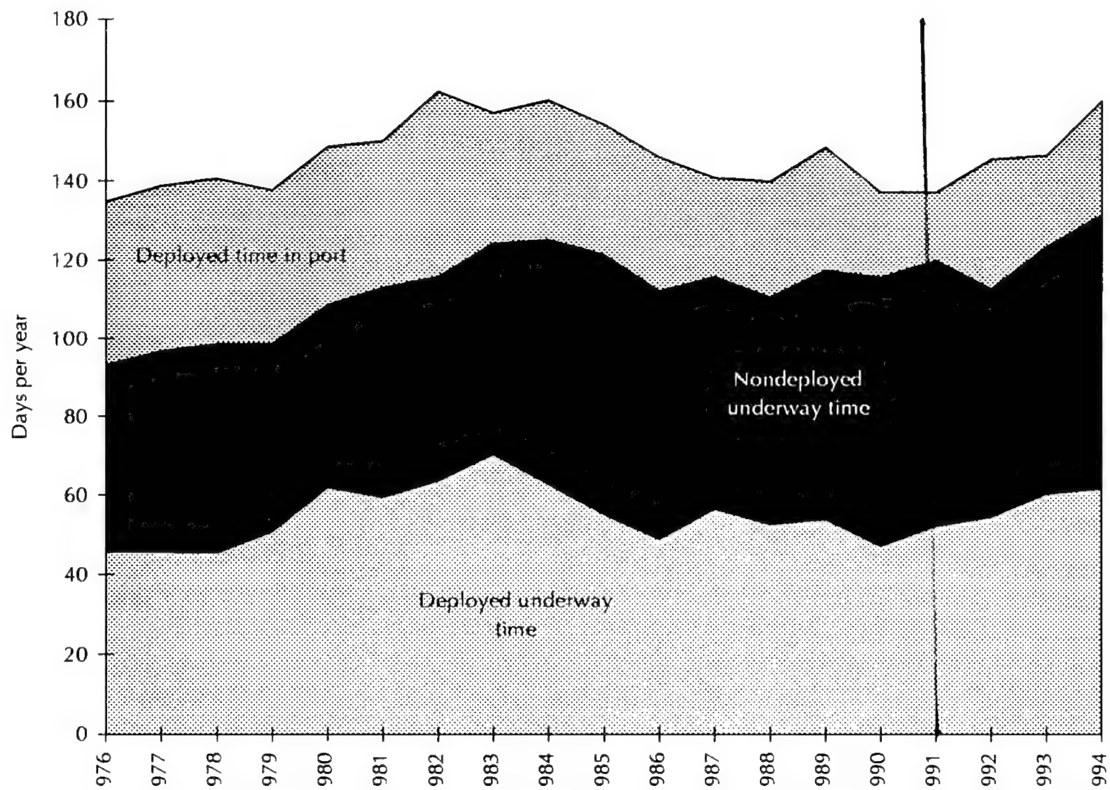
This figure shows that current operating conditions for many ship classes have indeed gotten better not worse—at least in terms of the number of ships required to meet forward presence. Some classes—most notably amphibious ships—still seem to be in as much demand today as they were in the 1970s and 1980s, even if in relative terms they are in less demand than surface combatants and submarines.

This provides a sense of how much demand there is for Navy forces (in historical terms), but it does not help us with the supply of ships that are available to fill that demand. Figure 23 puts that concern into

perspective. It shows that rather than easing up, OPTEMPO for the average ship has seen a steady, if unspectacular, rise.

To get a sense of what might be driving this increase in OPTEMPO, we looked at how the average surface combatant has spent its time over the past 20 years. Figure 24 displays this information.

Figure 24. Distribution of surface combatant activity, 1976–1994



It shows the amount of time the average surface combatant spends deployed and under way—meaning that it is out at sea steaming; deployed but in-port—meaning that it is tied to a pier in any number of ports of call around the world; and not deployed but under way—meaning that it has been out to sea less than 56 days in a row training for an upcoming deployment. In one sense, everything shown on the

chart is bad in that it keeps sailors away from their families. It is good, however, in the sense that everything on the chart depicts some type of activity that creates or maintains ready ships. The Navy appears to be reducing the time surface combatants have historically spent in port and increasing time spent steaming—both in the workup and deployment phase. This may mean that Navy personnel who deploy are working harder than ever—if one equates steaming with working. It certainly does not appear, at least in our view, to be so alarming as to invoke images of pending hollowness

Spare parts

Supply, like so many other aspects of Navy readiness, is multidimensional. It has a shore-side distribution aspect that involves the speed with which a spare is located and sent to the fleet. There is the question of transit time, i.e., the distance a part has to travel. Finally, there is the issue of how effective a ship's onboard supply shop is in making use of existing or potential inventories.

Previous research has shown that the size of a ship's aviation consolidated allowance list (AVCAL) and consolidated allowance list (COSAL) are positively correlated with the readiness of the platform and systems they support. One study found that the full mission capability (FMC) rate of aircraft dropped by 5 percent whenever the dollar value of a demand-based AVCAL was reduced by 30 percent [16]. A similar study found that FMC rates dropped 19 percent whenever AVCAL depth was reduced by 10 percent [17].

We looked at AVCAL and COSAL trends over time. This information is shown in figures 25 and 26. Figure 25 tells us the probability that a requested part is available when needed to keep a fighter-attack aircraft up and running. Figure 26 tells us the probability that a requested item is stocked on board a ship, whether or not it is available when requested. Thus, it evaluates the effectiveness of the stocking list not of supply availability per se. Gross effectiveness, on the other hand, measures readiness more directly. It reports the probability that a requested item is on board when needed. This data, which is depicted in figure 27, evaluates what is important for readiness in the short-run—whether a spare part is available when needed most to keep a system up and running.

Figure 25. Gross effectiveness of Navy fighter-attack aircraft, 1982–1994

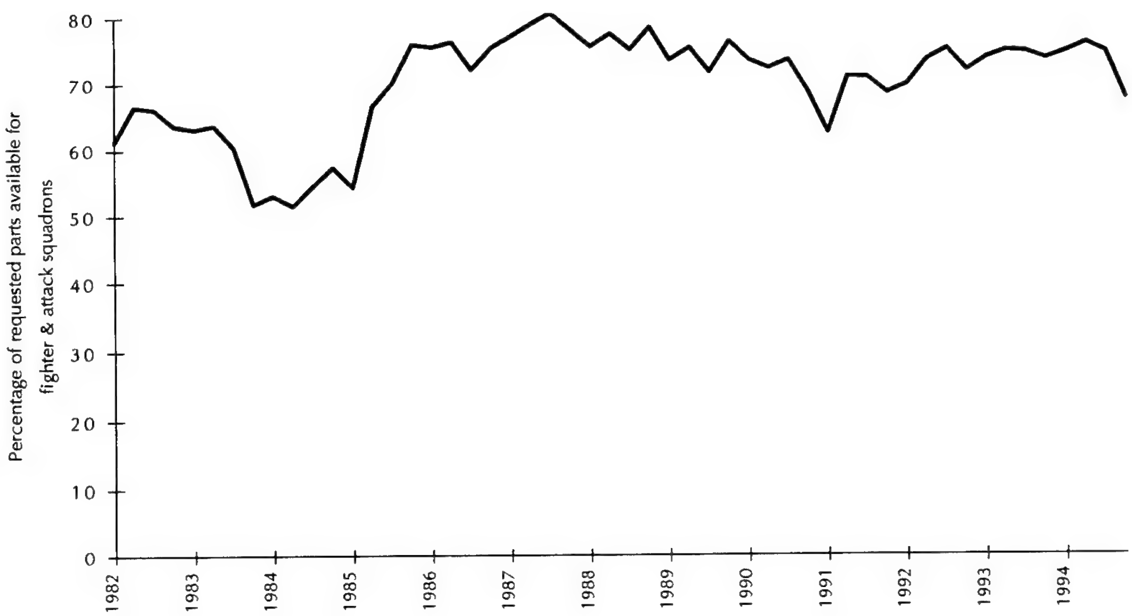


Figure 26. COSAL effectiveness of Navy ships, 1977–1994

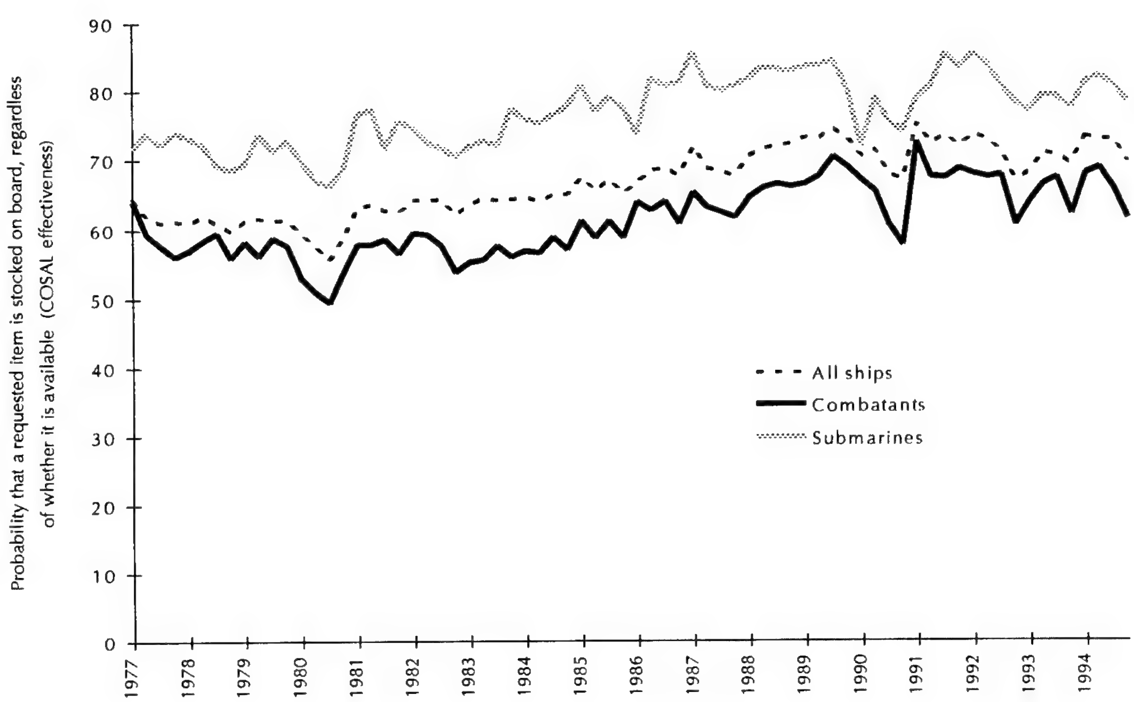
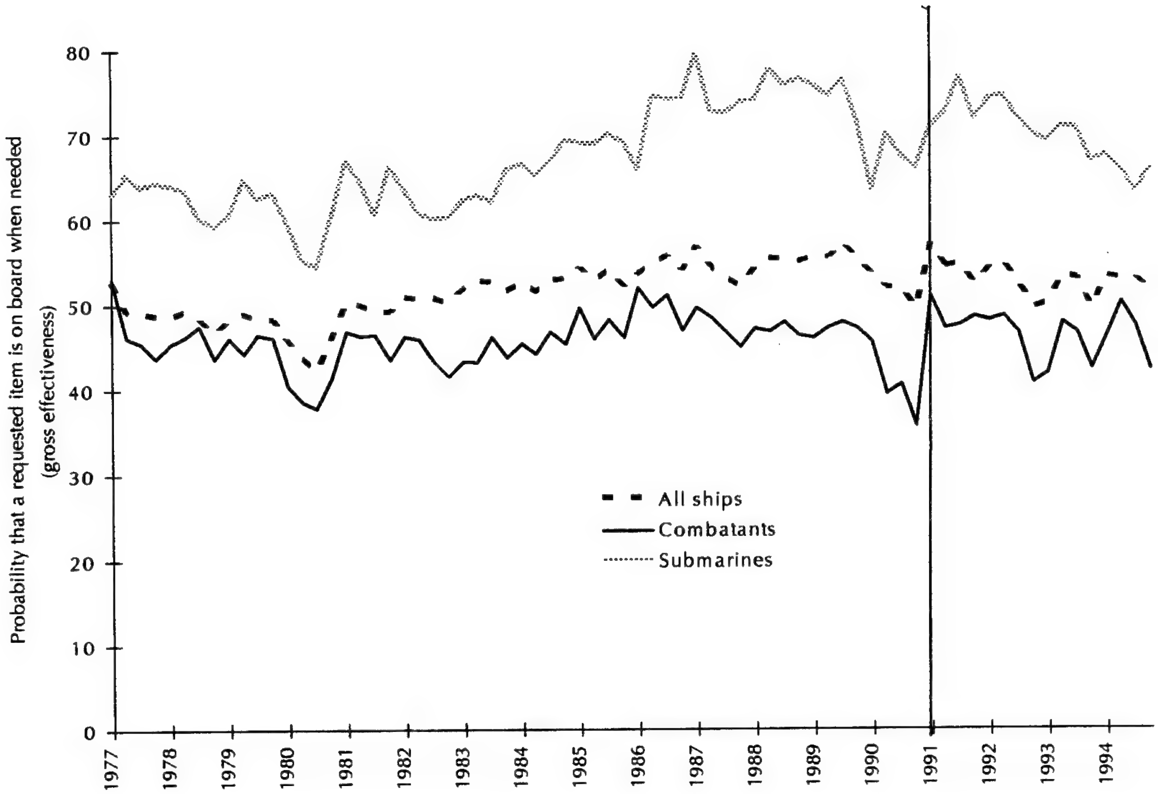


Figure 27. Gross effectiveness of Navy ships, 1977–1994



Insights *(for avoiding a hollow force)*

From this brief review of readiness trends, we gain some insights as to how we might avoid hollowness in the future. Most basic is the notion that unless we look at readiness over the long term—i.e., in terms of the way trends are moving, we risk over-reacting to meaningless, short-term fluctuations in the data.

A second issue to consider is presentation. Indexing offers real benefits to senior leaders who rarely have time to study all the numbers. By bundling indicators in like groups, however, senior decision-makers can become familiar with general trends without getting lost in the minutia entailed in large lists.

Finally, there is the issue of status, and on this score the Navy is doing well. Each indicator we've looked at suggests that Navy readiness

today is good. What the indicators don't tell us is what might signal downturns in Navy readiness, or what weight we should attach to an individual indicator—in the sense that it is more or less important than another one. This is the goal we turn to now.

Predicting readiness

There has long been a problem understanding how diverse resources come together to form a ready unit. One reason is that it is often hard to tell exactly which resource area exerts the strongest influence on a unit's capability to perform a given mission. In peacetime, we must rely on indirect means—via a vast collection of indicators—to help us assess and measure overall system performance. Indicators offer clues as to how well manned, equipped, supplied, and trained a unit is, which helps us understand what readiness looks like. What indicators often don't tell us is the combined effect they have on system performance or, more pointedly, what resource areas have the greatest impact on unit readiness.

The traditional notion has been to predict what readiness will look like based on the amount of funding that is available to meet some preset requirement. This, in itself, is not easy. Often, elaborate, computer-based models are used to help establish the level of funding required. These models are typically of the sort that make use of very specific details about the historical usage rates of spare parts. They contain ample data about the time it takes to fill a parts request; spares utilization rates; and the chances that a part is actually available when needed. Through simulation runs, the models try to determine the optimum level of spares necessary to achieve a specified readiness goal, such as a high MC rate.

An alternative approach to the problem of relating resource levels to readiness is the search for early warning indicators of readiness problems. The basic question here involves whether or not a "predictive" indicator of future readiness can be found. Such an indicator, in theory, could signal impending readiness problems before they become serious problems. This is clearly what many have in mind when they refer to predictive indicators. They assume that such indicators would allow sufficient time between the identification of a problem and the actions associated with correcting it—whether in the form of

redirecting resources or lobbying for more of them. Even if there is not enough warning to avoid a problem, there may be enough to localize it. This problem has two basic dimensions.

The first involves time. Predictions have a time component. They tell us something about the future, i.e., one thing that leads to another when viewed within a time continuum. A second element goes beyond the mere anticipation of problems to an explanation of their causes. It requires that predictions tell us something—perhaps empirically—about the way complex things interact. In essence, it tells us something we do not already know about the generative nature of a problem. Both are basic to solving problems. The former is important because it refers to timeliness—for without enough time, actions are not possible. The latter is important because it refers to the direction in which action is intended.

General approaches

We have begun to think about predictions as a specific way to forecast the future. Forecasting itself refers to any method used to determine information about a future state. Future readiness can be forecast in three basic ways [18]:

- Projections, which are forecasts based on the extrapolation of historical and current trends into the future. They are derived through analysis of trends and cycles, which can produce indicators that are useful for short-term forecasting—to identify when things are starting to deteriorate. Such indicators provide early warning several months to two years in advance, and they are analogous to the way economists have long viewed economic activity—in terms of leading, concurrent, and lagging indicators.

- Predictions, which (as our earlier discussion made clear) are forecasts based on explicit theoretical assumptions. These assumptions often take the form of theoretical laws (such as those governing the diminishing utility of money). The essential feature of a prediction is that it specifies the causes and effects that underlie a specific relationship. Predictions of this sort typically take the form of empirical models. The variables

used within these models are often useful in making long-term forecasts. An example is funding for aviation spares, which appears as an explanatory variable in the Navy's MC model. This type of indicator can spot possible trouble in the outyears. But it is subject to inaccuracies in the way the Navy's program objective memorandum (POM) is built because it will not necessarily signal imminent trouble.

- Judgments, which are forecasts based on subjective assessments of future states. These judgments may take the form of intuitive arguments, where assumptions about the insight, creative intellectual power, or tacit knowledge of stakeholders are used to support designative claims about the future. Their essential feature is that they are based on subjective judgments, rather than on empirical data or scientific theories. The Navy's Predictive Measures of Readiness (PMOR) effort, upon which so much of our work is based, is a classic example of this because it establishes a hierarchy of readiness indicators that show how one set of indicators affects a resource area, such as personnel, supply, or ship readiness. These insights were gained—not through scientific reasoning—but as a result of a rigorous staffing process that channeled the combined expertise of all participants toward the end goal of predictive indicators of Navy readiness.

Today we hear much discussion about how predictions can help forecast readiness. In general, this has meant using mathematical formulas—often in the form of closed regressions—that estimate the effect that changes in one or more variables will have on some dependent variable, usually sorties generated or MC/FMC rates. The key inputs in such models are typically derived from budget sources. They generally involve the number of dollars spent in broad categories such as spare parts and engine rework. Much of CNA's early hollow force work involved helping the Navy link similar budgetary inputs to operational outputs [19, 20, 21].

Such an approach holds great promise in terms of making more sophisticated budget submissions, but it often misses key aspects of the resource-to- readiness relationship. Specifically, the heavy emphasis on budget inputs often gives short shrift to intermediate inputs, such as logistics response time, COSAL effectiveness, personnel

quality, and time under way. These physical outputs are often a lot closer to real readiness than dollar expenditures, which can almost never be tracked to their source. Physical outputs, on the other hand, are tangible things that we can easily measure. There is also often a direct link to the things we care about in terms of readiness, such as sorties flown, exercise result, and even SORTS scores. In simple terms, we need to get better at adding up assets and relating them to readiness before we try to go one step further and figure out how dollars relate to readiness.

There are other reasons to view with skepticism models that rely too much on budgetary information. Often, the predictions derived from such models are the product of the dollar requirements that appear in budget submissions. If budgets are not fully funded, these models tend to predict that readiness levels will fall far below targeted levels [22]. Also, budgetary data change from POM year to budget year to execution year. Meaningful comparisons are possible only if values can be held constant.

Our approach

We took a different approach. Realizing the limitations in tracking dollars to resources, we concentrated on adding up physical things instead. In all, we collected and assessed more than 200 indicators of the readiness of Navy ships and aircraft. Each indicator captured in our dataset contains quarterly data dating back to the late 1970s—so that when we aggregate it by ship class we could see what it looked like during the hollow force period of that time. In addition to this longitudinal data, we constructed a rich sample of cross-sectional information—so that when we disaggregated the data we could compare different ship and aircraft types across the Navy. In all, we accumulated quarterly snapshots of every surface combatant within the Navy over a 15-year period. Our dataset contains about 5,000 separate observations. Table 4 lists some of the indicators we collected. (See appendix D for a complete listing of indicators.)

Table 4. Dataset of readiness indicators[a]

Ship	Aircraft	Personnel
Age of ships	Age of aircraft	Reenlistment rates
Number of training days	MC/FMC rates	First-term attrition
Number of days spent in maintenance cycle	Sorties flown	Average length of service
Deployed/nondeployed time	Cannibalization rates	Percentage of E5s with less than 4 years experience
OPPE exams	Flight hours	Civilian pay gap
Days steaming	Mean flight hours between failures	Percentage of recruits with HSDG
CASREPs reported	NMC due to maintenance	AFQT scores
COSAL effectiveness	Maintenance man-hours	Unemployment averages
Gross effectiveness	Size of AVCAL	Pay grade demotions
Quarter since last overhaul	I-level maintenance repair rate	Available E1-E9s (weighted by wage)
Time to fix a CASREP due to maintenance problems	Elapsed time to resolve maintenance action	Required E1-E9s (weighted by wage)
Time to fix a CASREP due to supply problems	Percentage of time squadron cannot fly safely	NEC fills
SORTS ratings	SORTS ratings	SORTS ratings

a. Each indicator contains quarterly data by ship (surface combatants only) and by aircraft squadron.

Modeling readiness

Models express the interaction between a variety of things, such as controllable decision variables (like the amount of scheduled procurement in a given year), uncontrollable variables (like parts failures), and measures of interest (like fuel consumption). When done correctly, empirical models contribute to our understanding the way complex systems function. When done incorrectly, they can be misleading.

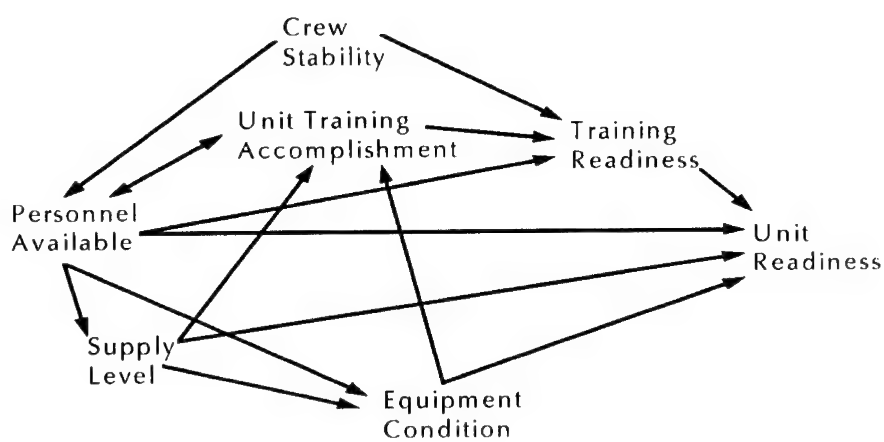
Successful modeling requires analysts to think creatively about the activity under study. It also requires the collection of large amounts of data—all of which need to be analyzed to ensure a proper understanding of the problem at hand. The previous section detailed the

data we have collected. What it did not describe was our analysis plan. We knew, for instance, that each of the indicators listed had some bearing on Navy readiness. But what was not clear was the combined effect they have on readiness as a whole. Which exerted the greatest impact on unit readiness? And even more to the point, how could we capture this in a mathematical formula? What empirical structure should readiness take?

Understanding causal relationships

We began by constructing a theoretical framework to help us assess the relative importance of these indicators. We used an analytical model first designed to link resource levels to unit readiness and defense capability [23, 31]. This model describes a system of interrelationships among SORTS resource areas and unit readiness. The Systems View of unit readiness, outlined in figure 28, holds that the specific level of training accomplishment achieved by a unit depends on the level of resources devoted to personnel and supplies, as well as the general condition of equipment.

Figure 28. The Systems View of unit readiness



The Systems View treats training accomplishment in much the same way as SORTS does—as the demonstrated ability of a platform to perform to its design capability. However, unlike SORTS, the Systems View holds that training accomplishment paints only a partial picture of training readiness. Ship manning and personnel quality, which we already discussed, as well as the amount of time a ship's crew has had to work together, all play a role in explaining why two ships with identical amounts of training perform to different standards [24, 25]. Training accomplishment is a contributor to training readiness, and a useful proxy for it. Ideally though, training readiness would be measured by unit performance.

Underlying each of the resource areas displayed in figure 26 are a set of conceptual models that describe the factors that influence each of the SORTS resource areas. The OPTEMPO budget is important to training accomplishment, but it is not the sole driver. Training accomplishment requires that capable personnel, functioning equipment, and necessary supplies be readily available for training purposes. How well these resource areas are maintained tells us more about training accomplishment than budgetary goals, which often don't reflect actual usage rates.

Available personnel is characterized by the quality and quantity of personnel assigned to a unit. These attributes are reflected in measures of the innate ability of the crew, their formal education, the amount of individual and unit training they receive, crew stability, and their collective experience. Additional factors, such as PERSTEMPO and unit leadership also affect morale. Personnel is a primary input to unit readiness. It affects every other resource area as well.

Equipment condition is ideally measured in terms of operational availability of equipment. Operational availability is determined, in turn, by the failure rate and the speed of repair of a piece of equipment. Failure rate is modeled as dependent upon the personnel who operate and maintain the equipment, the type and level of operations, maintenance policies, and the inherent reliability designed into an equipment. The speed of repair is also dependent upon personnel and operating conditions. In addition, on-board spares, repair

equipment, and manuals are also important. Repairability built into the design of equipment, as well as transit times and off-site repair activities, are important in determining if a part can be repaired at the organizational level, and how long more serious repairs will take to fix.

Supply readiness, which includes availability of fuel, ordnance and spares, is determined not only by resupply assets, but by the level and type of operations as well as the personnel who are responsible for maintaining supplies.

Model specifications

Specification, choosing how to mathematically represent the influence these resource areas have on one another, is the real trick of econometrics. We designed a system of equations built around the theoretical model described above.[8] In doing so, we used what economists call a production function. Under this formulation, readiness, at least at the unit level, is a product of the status of underlying resources or inputs. As such, we can describe it as a function of several independent variables, such as personnel, supply, material condition of equipment, and training. We can summarize this framework in the following equation:

$$R = f(P, S, E, T) ,$$

where P, S, E, and T stand for personnel, supplies, equipment, and training, respectively. The final output of this process is thought to be readiness—as defined earlier as the ability of a unit to realize its design potential. This can be quantified if we measure it in terms of whether a unit performs to certain prescribed standards. SORTS, to a limited degree, is a proxy for this because it contains information about whether a given unit (or ship) has enough resources on hand to meet required goals. This works rather well for the more defined subcategories within SORTS and less so for the more gameable ones, such as the training subcategory. This is especially true because

8. Documentation is provided in CNA Research Memorandum 95-239, *A New Approach to Ship Readiness Modeling*, by Laura J. Junor, April 1996.

training, unlike the other SORTS categories, is not bounded by numbers. At least in theory, more training always means higher readiness.

The modeling approach chosen made use of all four SORTS resource areas. It consists of a series of interconnected equations with the percentage of time a unit spends in C1 for any given SORTS resource area as the dependent variable. This design allowed us to test a number of variables to determine whether they were statistically related to SORTS. The result is a series of mutually supporting equations that estimate the effect certain readiness indicators have on the percentage of time the average Navy surface combatant spends in C1.

The equations reflect layered effects on readiness. The initial equation explains overall SORTS (the percentage of time a ship is in C1 for each of the four resource areas). There are equations for each resource area as well, which are summarized in table 5. All variables shown within this table are associated with changes in at least one of the four SORTS resource categories.

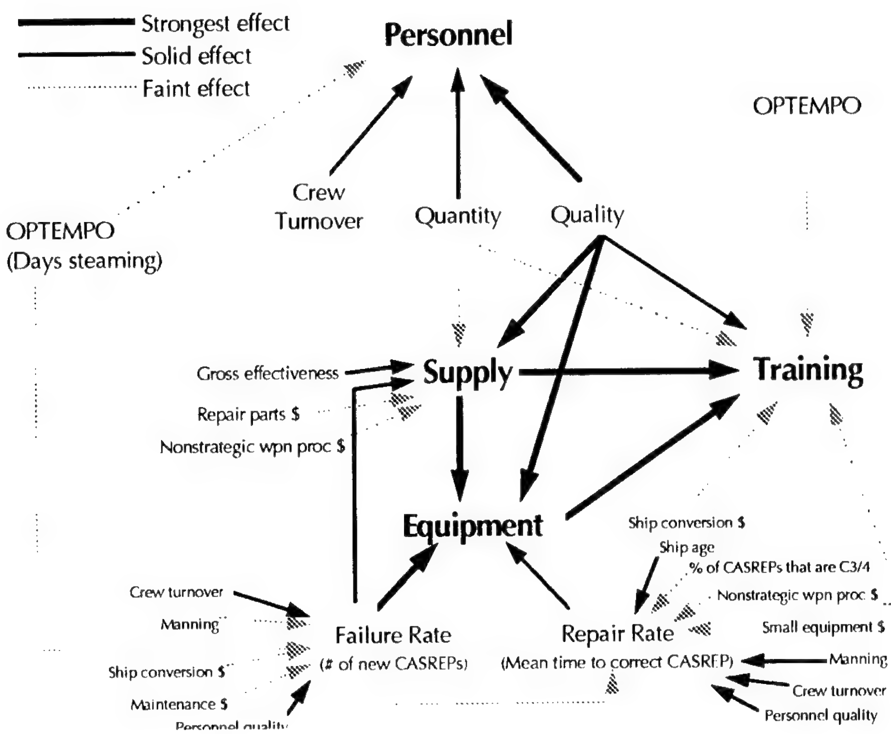
Table 5. Significant factors affecting Navy ship readiness

Personnel	Equipment		Supply	Training
	Failure rate	Rate of repair		
Personnel quality	Personnel quality	Personnel quality	Personnel quality	Personnel quality
Manning	Manning	Manning	Manning	Manning
Manpower procurement	Supply predicted	Number of new CASREPs	Ship spares funding	Supply predicted
OPTEMPO (steaming days under way)	OPTEMPO (steaming days under way)	Maintenance funding	Time spent waiting for a part	Equipment predicted
	Ship conversion funding	Ship age	Nonstrategic weapons procurement	Nonstrategic weapons procurement
	Deployment cycle	% of CASREPs that are C3/C4	Number of new CASREPs	OPTEMPO (steaming days under way)
	Crew turnover	Crew turnover	Gross effectiveness	Ship conversion $
			Repair parts $	

Table 5 also shows that equipment condition is really the product of three interrelated equations—the first two explain equipment failure and rate of repair; the last one explains how these two aspects of

equipment condition combine to affect the amount of time a ship is in C1 for equipment. A final equation summarizing the combined effect that all four estimated resource categories have on the percentage of time the average surface combatant spends in C1 is then estimated. Figure 29 outlines the relative effect that these resource areas have on one another [24].

Figure 29. Graphical representation of magnitude of effect that one resource area has on other resources



This all suggests that readiness is a complex process. But we now have some evidence that shows how it works. From this figure, we know that personnel quality affects all resource areas. It has a ubiquitous presence in all areas of Navy readiness. Manning also has an impact but not nearly as great. What's more, OPTEMPO is seen to have a steady, if somewhat unassuming, effect on nearly every phase of readiness.

What degree of confidence do we have in these findings? In technical terms, the chances of these findings being the result of sampling error are less than 1 out of 100. This is not to say that there are not some things missing from our picture. As with any model, it is no better than its inputs, and there are some missing pieces. For example, we had no good proxies for on-hand ordnance, a key aspect of ship training and supply SORTS. We would like to know more about the type of training individual ships conduct and the proficiency level they reach. We would have benefited from greater understanding about how technological advances in propulsion and weapons systems affect readiness—and how improvements in command and control procedures have influenced ship readiness. Finally, we need to think about how schoolhouse training data might affect our picture of personnel quality. It is reasonable to assume that had we factored in such things, they would also prove to be closely associated with ship readiness.

Despite these limitations, the model does offer us a way to track how change in one variable, such as personnel quality or OPTEMPO, will affect unit readiness. It also tends to crystallize for us those resource areas that seem to play the greatest role in improving unit readiness. This may be very useful when preparing budgets and in helping to pick out those areas that need to be watched for early warning signs of deterioration.

Insights *(for avoiding a hollow force)*

Overall findings suggest that personnel quality is probably the most important readiness resource, at least in terms of the total effect on unit readiness. As shown in figure 29, we consistently found that personnel quality influences Navy readiness. Our results confirm what we had already concluded—good people tend to do everything better than bad people. As quality of personnel improves, so too does readiness.

Another key finding is the notion that SORTS, generally thought of as unreliable as anything but a status indicator of unit readiness, is quite useful in helping us understand the complex process by which readiness is achieved. Others have successfully created models that

relate certain resource categories to measurable outputs, such as MC rates and sorties, but we have built what we believe is a much more robust model. This model shows, empirically, the interdependence of different dimensions of readiness. This model helps us understand how personnel quality and other factors influence the percentage of time a ship stays C1 for personnel, supply, equipment, and training. In so doing, it helps substantiate SORTS as a worthwhile indicator of unit readiness—while avoiding questions of requirements validity.

Training accomplishment, as measured by SORTS, is also found to improve as steaming time increases. This condition persists up until steaming reaches 52 days per quarter, after which it begins to degrade—slowly at first then faster as steaming time rises. This is consistent with what other research has found—specifically, that training readiness begins to deteriorate somewhere around the 40-plus day per quarter mark [24, 25]. The implication here is that the Navy's leadership must watch the crest of this slope very carefully and avoid any unnecessary excesses.

A related insight involves the effect that deployments have on ship readiness. Our analysis suggests that ship readiness on the deployed side looks very similar to ship readiness on the nondeployed side. The difference is that hiccups in the system affect deployed ships more than nondeployed ships. For example, crew turnover has been found to be associated with the number of new CASREPs a ship experiences. This is true regardless of ship deployment status. What is different is the effect this turnover has on ship readiness depending upon when it happens—if deployed, expect a big drop in readiness; if not deployed, don't fear it as much.

Appendix A: Summaries of research on determinants of readiness

The appendix tables are of two types. The tables summarize the approach of each study, its broad findings, and the main determinant of readiness being studied. The quantitative estimates tables provide sample magnitudes of effect consistent with the results of each study. Together, these tables provide a sense of the literature on resources-to-readiness that can put our modeling results in perspective [27]. For more on the state on the state of readiness research, see [28].

Determinant—OPTEMPO	Abstract	Source
Barrels of fuel consumed by ship, underway days; underway ship activities flying hours	*Summary*: Examines the effect of underway time and how it is used (transit, training...) on training readiness *Findings*: "We reviewed the association between nondeployed activities and training readiness, using a variety of measures for both ships and aircraft. Results are consistent in that they uniformly report a measurable payoff to operational training."	CNA Professional Paper 427, *OPTEMPO and Training Effectiveness*, by Linda Cavalluzzo, December 1984
Time under way	*Summary*: Explores the relation between various measures of training readiness, and OPTEMPO using regression methodology applied to quarterly data for individual ships. *Findings*: OPTEMPO improves various measures of training readiness, but incremental improvements decrease as OPTEMPO rises, peaking at between 25 and 40 days per quarter.	CNA Research Memorandum 86-123, *OPTEMPO and Ship Readiness*, by Dean Follman, et al., June 1986

Determinant—personnel	Abstract	Source
AFQT, high school degree	*Summary*: Investigates the relationships between ship material readiness and the percentage of the enlisted crew that tested in the top half of the ability distribution on the AFQT and that are also high-school diploma graduates. *Findings*: Higher crew quality corresponds to a higher material readiness.	CNA Research Memorandum 88-254, *Enlisted Crew Quality and Ship Material Readiness*, by Aline Quester, April 1989
Length of deployment, time under way but not deployed, pay	*Summary*: Uses a database of retention decisions of individual sailor FY1979-88 to explore the dependence of retention rates on time under way and pay. *Findings*: Extending deployment decreases the retention rate for 4-year obligors by about 2.1 percentage points. This can be offset by an increase of pay of about 5 percent or an increase of all SRBs by one level.	CNA Research Memorandum 91-150, *Personnel Tempo of Operations and Navy Enlisted Retention*, by Timothy Cooke, et al., February 1992
Turnover/new crew rates	*Summary*: Examines trends in turnover rates. Estimates the historical relationships between turnover and ship readiness/material condition. Analyzes alternative policies that could limit the impact of turnover. *Findings*: Increasing the fraction of the crew which is new reduces readiness.	CNA Research Memorandum 89-169, *Enlisted Crew Turnover and ship Readiness: Review, Refinements, and Recommendations*, by Alan Marcus, July 1989
Manning, turnover/new crew	*Summary*: Estimates relationships between manning and turnover and ship material condition. *Findings*: Manning has a positive effect on material condition and new crew has a negative effect.	CNA Professional Paper 467, *Ship Material Readiness*, by Aline Quester, February 1991

Determinant—supply	Abstract	Source
AVCALs	*Summary*: Explores the cost-versus-readiness relationship for alternative AVCALs. Two sparing models were considered—traditional demand-based sparing and readiness-based sparing (RBS). *Findings*: RBS allows the Navy to spare to readiness objectives and still lower AVCAL costs by as much as 30 percent. Uses the Air Logistics Model for calculations—a simulation model capable of replaying historical cruises under varying conditions.	CNA Research Memorandum 93-20, *Aviation Logistics Support: Retail Sparing Issues*, by Anne Hale, et al., June 1993
COSAL, ship configuration data	*Summary*: Uses models to estimate operational availability and supply effectiveness as a function of spare-parts support levels and configuration data. *Findings*: Both COSAL and configuration data have important effects on availability and supply effectiveness. Maintaining good configuration data is a cost-effective way of making the COSAL more useful.	CNA Research Memorandum 90-149, *The Value of Improving Data on Ship Configuration*, by Tibbits, Jondrow, and Lutz, August 1990

Appendix B: Quantitative estimates of effect

Determinant—OPTEMPO	Readiness indicator	Stat. sig?[a]	Illustrative magnitude of effect (and illustrative arc of elasticity[b]	Source
Days under way per quarter	Scores on low-visibility piloting exercise	Yes	Small: Increasing OPTEMPO from 30 to 31 days raises score by .2 points, e.g., from 90 to 90.2. (Arc elasticity = .07)	CRM 86-123
Days under way per quarter	Pass rate on OPPE	No		CRM 86-123
Flying hours	Boarding rates	N/A	Raising flying hours from 399.5 to 479.5 (interval midpoints) per squadron per month raises average boarding rate from 90.1 percent to 93.2 percent. (Arc elasticity = .19)	CNA Professional Paper 427
Fuel budget	Fraction of time in C1 (SORTS)	Yes	"For deployed ships, a 1-percent fuel budget increase is associated with an 8-percent increase in C1 time and a decrease in all lower readiness categories" (Arc elasticity = .8)	CNA Professional Paper 427
Flying hours devoted to bombing practice	Average miss distance for bombing runs	Yes	"A 1-percent increase in flying hours devoted to bombing practice is associated with a 1/2-percent reduction in average miss distance." (Arc elasticity = .5)	CNA Professional Paper 427
Flying hours	Grades in Operational Readiness Evaluations	N/A	"Squadrons in the Pacific Fleet average less than 80 percent as many monthly pre-ORE flying hours as those in the Atlantic Fleet.[c] Only 39 percent of Pacific Fleet squadrons received scores in the top two ORE categories, compared to 63 percent for the Atlantic Fleet. (Arc elasticity = 2.1)	CNA Professional Paper 427
Flying hours	Boarding rates	N/A	Raising flying hours from 399.5 to 479.5 (interval midpoints) per squadron per month raises average boarding rate from 90.1 percent to 93.2 percent. (Arc elasticity = .19)	CNA Professional Paper 427

a. Stat. Sig? = Is the effect statistically significant?

b. Arc elasticity: An arc elasticity of .7 means that a 10-percent change in the determinant leads to a 7-percent change in the readiness index.

c. "Assuming roughly equal total funding, this difference could be due to greater demands during the longer deployments in the Pacific." Arc elasticity is calculated using 80 percent for the Pacific Fleet.

Determinant—Personnel	Readiness indicator	Stat. sig?[a]	Illustrative magnitude of effect (and illustrative arc of elasticity[b]	Source
Pay	Retention rate	Yes	For 4-year obligors, increasing pay by 5 percent raises the retention rate by about 2.3 percentage points from an average of 28 percent. (Arc elasticity = 1.6)	CRM 91-150
Pay	Retention rate	Yes	An increase of all SRBs by one level increases the retention rate by about 2.5 percentage points.	CRM 91-150
Manning	Percent of time free of C3/C4 CAS-REPs	Yes	As manning increases from 86.7 percent to 92.06 percent, the percent time free of CASREPs for Spruance class ships increases from 54.6 to 69.92. (Arc *elasticity* = 4.1)	CNA Professional Paper 467
Turnover	Percent of time free of C3/C4 CAS-REPs	Yes	As new crew (within 3 months) decreases from 13.03 to 9.63, the percent time free of CASREPs increases from 62.82 to 69.92. (Arc elasticity = .36)	CNA Professional Paper 467
Percentage of crew that is high quality—AFQT above median and high school diploma	Percent time free of CASREPs for various surface combatants	Yes	For Knox class ships, increasing the percentage of high quality crews from 50 to 51 percent raises predicted time free of CASREPs from 68.5 percent to 70.4 percent. (Arc elasticity = 1.4)	CRM 88-154
Length of deployment	Retention rate	No	For 4-year obligors, increasing the length of deployment from about 6 months (interval midpoint) to 8 months decreases the retention rate by about 2.1 percentage points from an average of 28 percent. (Arc elasticity = .25)	CRM 91-150
Time under way but not deployed	Retention rate	Yes	For 4-year obligors, increasing time under way but not deployed by 25 percent (from 20 percent of the time to 25 percent of the time) decreases the retention rate by about .7 percentage points from an average of 28 percent. (Arc elasticity = -.11)	CRM 91-150
Turnover/new crew	Probability of deploying C1 for training	Yes	For ships in their first deployment since overhaul, a decrease in new crew from 11.8 percent to 19.8 percent increases the estimated probability of deploying in C1 status for training from .82 to .84. (Arc elasticity = .27)	CRM 89-169

Determinant—Personnel	Readiness indicator	Stat. sig?[a]	Illustrative magnitude of effect (and illustrative arc of elasticity[b]	Source
Turnover/new crew	Probability of deploying C1 for training	N/A	A similar improvement in the probability of deploying C1 for training is produced by (1) a 4-percent decrease in new crew (less than 3 months aboard); (2) an increase in OPTEMPO while nondeployed of 1.8 days per month (for instance, from 10 days per month to 11.8 days per month); (3) a 2.7-percent increase in manning, e.g., from 280 to 287 persons.	CRM 89-169

a. Stat. Sig? = Is the effect statistically significant?

b. Arc elasticity: An arc elasticity of .7 means that a 10-percent change in the determinant leads to a 7-percent change in the readiness index.

Determinant—Supply	Readiness indicator	Stat sig?[a]	Illustrative magnitude of effect (and illustrative arc of elasticity[b]	Source
Cost of demand-based AVCAL (shipboard stock of spare parts)	FMC rate for carrier airwing	N/A[c]	30-percent cost reduction leads to a decline in airwing FMC from .64 to .59 (p. 4). (Arc elasticity = .21)	CRM 93-20
Cost of readiness-based-sparing AVCAL	FMC rate for carrier aircraft	N/A	30-percent cost reduction leads to a decline in airwing FMC from .67 to .62 (p. 4). (Arc elasticity = .22)	CRM 93-20
Cost of COSAL	Estimated availability	N/A	Taking CIWS as a case study, as the value of the COSAL for CIWS increases from $600,000 to $800,000, availability increases from about .74 to about .86 (read from graph on p. 30). (Arc elasticity = .52)	CRM 90-149
Configuration data	Estimated availability	N/A	As configuration data are improved (to recognize a major MOD, such as ORDALT 15410 for the CIWS), availability increases from about .74 to about .86 (roughly the same effect as for the extra COSAL described above)	CRM 90-149

a. Stat. Sig? = Is the effect statistically significant?

b. Arc elasticity: An arc elasticity of .7 means that a 10-percent change in the determinant leads to a 7-percent change in the readiness index.

c. N/A = not applicable

Appendix C: Measuring the readiness baseline and the direction in which readiness is moving

This appendix explores two related questions:

- What should be the goal or baseline for readiness in the Navy? How far away from this goal should we get before we start to worry?
- Is readiness moving toward traditional hollowness, away from hollowness, or in a different direction altogether?

We based our answer to these questions on the 23 variables listed below. These data are by quarter (1977–1994) and by ship.

SORTS-based variables:

- Personnel
  - — (1) Percentage of time in the quarter that the Personnel SORTS score was C1 for deployed ships
  - — (2) Percentage of time in the quarter that the Personnel SORTS score was C1 for nondeployed ships
  - — (3) Percentage of time that the Personnel SORTS score was C1/C2 for deployed ships
  - — (4) Percentage of time in the quarter that the Personnel SORTS score was C1/C2 for nondeployed ships.
- (5-8) Equipment: Variable similar to those for personnel—Percent of time in the quarter that the Equipment SORTS score was C1 and C1/C2 for deployed and nondeployed ships.
- (9-12) Supply: Percentage of time in the quarter that the Supply SORTS score was C1 and C2, for deployed and nondeployed ships.

- (13-16) Training: Percentage of time in the quarter that the Training SORTS score was C1 and C2, for deployed and nondeployed ships.

CASREP variables:

- (17-18)CASREPs: Percentage of time free in a quarter from C3 and C4 CASREPs, separately for deployed and nondeployed ships.

Personnel quality variables:

- (19) HSDG: Percentage of the crew with a high school diploma.
- (20) AFQT: Percentage of the crew who scored in the upper mental group on the AFQT.
- (21) Fast promotion: Percentage of the crew who made E5 in 4 years or less. Denotes the need to promote fast in order to fill shortages.
- (22) Demotions: Percentage of the crew that had a higher paygrade last quarter.
- (23) LOS: Average length of service measured in months.

Readiness standards

The first question is: What is a meaningful goal or baseline for readiness? A second question is how far away from this goal should we get before we start to worry?

The answer we propose makes use of the recollections of the low readiness of the late 1970s and early 1980s. We ask whether recent data remind us of periods of low readiness or of periods of higher readiness. We used cluster analysis to break our sample period (shown in table 6) into clusters that best explain the data. In other words, we wanted to minimize the variation within the clusters. We used SAS Institute Inc. software—PROC CLUS with METHOD=WARD.

Describing the seven clusters

Table 6. Description of the clusters

Name	Included observations
Late 1970s	All quarters in 1977, 1978, and 1979
Early 1980s	All quarters in 1980, 1981, and 1982
1983	All quarters in 1983, first quarter in 1984
1984/1985	Second and third quarter of 1984; first, second, and third quarter of 1985
Mid 1980s buildup	Fourth quarters in 1984 and 1985; all quarters in 1986 and 1987; first and third quarters of 1988.
1980s/1990s	Second and fourth quarters of 1988; all quarters of 1989 through 1992
Recent	All quarters of 1993 and 1994

To get a rough idea of where the clusters stood in relation to each other, we summarized the readiness indicators by computing their first principal component. We then averaged each principal component within the clusters.

As noted in the main text, principal component analysis is a statistical technique used to summarize multiple variables or indicators. It collapses these multiple indicators into an index called principal components. The first principal component could be looked at as an average of the different indicators where the averaging technique is chosen to best explain the data. We standardized each indicator so that each one had an average of 0 and a standard deviation of 1.

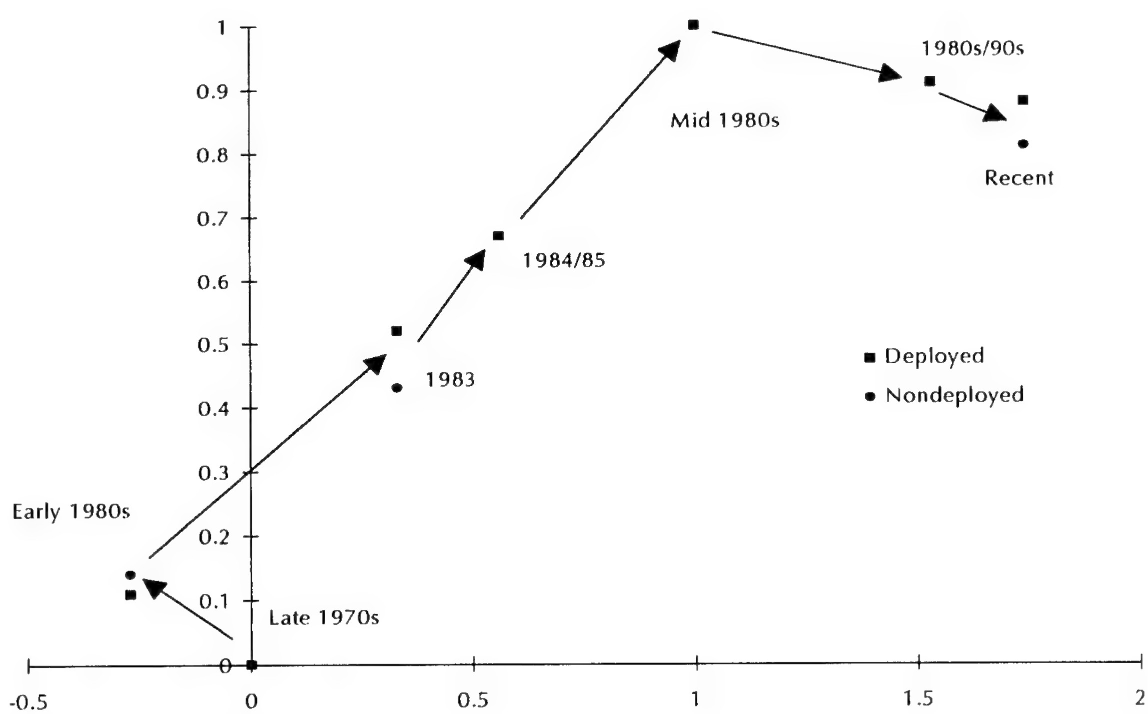
We calculated the first principal component for all of the indicators and then for smaller groups of indicators. The average values by cluster of the first principal component are shown in table 7 and figure 30. The numbers in parentheses are the principal components rescaled so that the late 1970s is zero and the mid 1980s is one. Thus, a .95 represents a 5-percent distance from the mid 1980s back toward the late 1970s.

Table 7. Principal components

Cluster	All variables	Personnel quality	Deployed SORTS	Nondeployed SORTS
Late 1970s	-1.42[a] (0)	-.95 (0)	-1.52[a] (0)	-1.55[a] (0)
Early 1980s	-1.33 (.04)	-1.24[a] (-.27)	-1.26 (.11)	-1.18 (.14)
1983	-.48 (.41)	-.59 (.33)	-.24 (.52)	-.46 (.43)
1984/1985	.11 (.67)	-.35 (.56)	.13 (.67)	.16 (.67)
Mid 1980s	.85 (1)	.11 (1)	.94[b] (1)	.98[b] (1)
1980s/1990s	.74 (.95)	.68 (1.53)	.71 (.91)	.77 (.91)
Recent	.90[b] (1.02)	1.82[b] (1.74)	.65 (.88)	.52 (.81)

a. Lowest cluster
b. Highest cluster

Figure 30. Principal components for seven readiness clusters[a]



a. Scaled: late 1970s = 0 and mid 1980s = 1.

The late 1970s have the lowest value of the principal components calculated using all variables and the lowest value for the principal components using deployed and nondeployed SORTS variables. This supports the notion that this represents a period of "hollowness" to which the Navy does not want to return. The first principal component for personnel quality was also low during the late 1970s, but even lower in the early 1980s, reinforcing the common belief that the early 1980s were a period of personnel problems.

At the other end of the readiness spectrum, the period of the mid-1980s buildup had the highest average for the principal component for deployed and nondeployed SORTS. The recent cluster had the highest value of the first principal component for personnel quality and the first principal component for all the data.

The two clusters for the 1983- and 1984/1985 periods represent a transition to improved readiness. The cluster "1980s/1990s" represents a slight dip in readiness, as measured by SORTS, but not as measured by personnel quality.

Direction

We can now ask the question, has the move from the mid 1980s to the recent period been away from or toward the late 1970s? Figure 30 answers this question: The move has been in a new direction. We are now as far away from hollowness as during the mid 1980s' buildup and will be moving farther away—but we are not moving in the same direction as the initial movement out of hollowness, from the late 1970s to the mid 1980s.

Figure 30 provides a clue as to the nature of these different directions. The move from the late 1970s to the mid 1980s emphasized unusual personnel problems—as indicated by both SORTS personnel and personnel quality. The move from the mid 1980s to the more recent data emphasizes an unusual contrast between personnel quality, which has been rising steadily, and the modest decline in SORTS scores, especially for nondeployed ships.

Appendix D: Indicators of Navy ship readiness

The following tables list the base indicators evaluated as part of this study. In most cases, the actual number of indicators considered was much larger owing to the way data was aggregated and sorted, i.e., by month, by quarter, by year, and by deployment status.

Table 8. Aggregate indicators of ship readiness

Indicator	Definition	Data availability	Source	CNA archives	In CNA model[a]
SORTS (Overall)	The percentage of time a unit spends in C1	1977-94,	WWMCCS	Yes	Yes
SORTS (Overall)	The percentage of time a unit spends in C2	1977-94,	WWMCCS	Yes	No
SORTS (Overall)	The percentage of time a unit spends in C3	1977-94,	WWMCCS	Yes	No
SORTS (Overall)	The percentage of time a unit spends in C4	1977-94,	WWMCCS	Yes	No
SORTS (Overall)	The percentage of time a unit spends in C5	1977-94,	WWMCCS	Yes	No
Number of days ship deployed	A ship is deployed if it is out of its home-port and not in overhaul for more than 56 days	1977-94,	EMPSKDs	Yes	No
Time since ship was in overhaul	Time since the ship was last in overhaul status	1977-94, monthly	EMPSKDs	Yes	No
Time since last deployment	Amount of time that has passed since last time ship was last deployed	1977-94, monthly	EMPSKDs	Yes	Yes
INSURV inspection rates	Number of ships that underwent an INSURV inspection compared to those that failed	1977-94, monthly	EMPSKDs	Yes	No
Days steaming	Amount of time a ship spent steaming underway.	1977-94, monthly	EMSKED	Yes	Yes
OM,N funding	Operations and maintenance accounts pay expenses necessary for support of Fleet ops, civilian employee pay, travel and transportation, training, consumable supplies, recruiting and advertising, & base ops	1981-94, annual	VAMOSC	No	No

a. Refers to whether a specific indicator is in CNA's final form, regression model (meaning that it has been found to be statistically associated with a predictor variable contained within the model).

Table 9. Personnel indicators of ship readiness

Indicator	Definition	Data availability	Source	CNA archives	In CNA model[a]
SORTS (Personnel)	Percentage of time a unit spends in C1 for personnel	1977-94,	WWMCCS	Yes	Yes
SORTS (Personnel)	Percentage of time a unit spends in C2 for personnel	1977-94,	WWMCCS	Yes	No
SORTS (Personnel)	Percentage of time a unit spends in C3 for personnel	1977-94,	WWMCCS	Yes	No
SORTS (Personnel)	Percentage of time a unit spends in C4 for personnel	1977-94,	WWMCCS	Yes	No
SORTS (Personnel)	Percentage of time a unit spends in C5 for personnel	1977-94,	WWMCCS	Yes	No
Personnel quality index	An index summarizing a number of indicators related to personnel quality	1977-94,	EMR	Yes	Yes
Weighted manning	Crew manning relative to M+1 requirements for all enlisted personnel on a ship, weighted by paygrade	1977-94, quarterly	EMR	Yes	Yes
High-school degree	Percentage of ship's crew that has a high-school degree	1977-94, quarterly	EMR	Yes	No
AFQT test scores	Percentage of ship's crew that scored in upper mental group (Cats I, II, & IIIA)	1977-94, quarterly	EMR	Yes	No
Demotions	Percentage of ship's crew that had a higher paygrade the previous quarter	1977-94, quarterly	EMR	Yes	No
Length of service	The average length of service for enlisted members of a ship's crew	1977-94, quarterly	EMR	Yes	No
Frequency of rapid promotions	The percentage of E5s and above who were promoted with less than 4 years of experience	1977-94, quarterly	EMR	Yes	No
Crew turnover	The percentage of the crew that was not there 3 months earlier	1977-94, quarterly	EMR	Yes	Yes
Crew turnover	The percentage of the crew that was not there 6 months earlier	1977-94, quarterly	EMR	Yes	No
NEC fills	Percentage of time the primary NEC matches a sailors' primary job	1977-94, quarterly	EMR	Yes	No
First-term attrition	Percent of crew members who attrite prior to completion of end of obligated service	1977-94, quarterly	EMR	Yes	No
Ratio of officers to enlisted	Number of officers to enlisted onboard an individual ship	1977-94, monthly		Yes	No
Reenlistment rates	Percentage of crew members who reenlist from one month to the next		EMR	Yes	No
Manpower funding	This is the cost of the services of all ships manpower, as reported by Navy Finance Center from JUMPS	1978-94, annual	VAMOSC	Yes	No

a. Refers to whether a specific indicator is in CNA's final form, regression model (meaning that it has been found to be statistically associated with a predictor variable contained within the model).

Table 10. Material condition indicators of ship readiness

Indicator	Definition	Data availability	Source	CNA archives	In CNA model[a]
SORTS (Equipment)	Percentage of time a unit spends in C1 for equipment	1977-94,	WWMCCS	Yes	Yes
SORTS (Equipment)	Percentage of time a unit spends in C2 for equipment	1977-94,	WWMCCS	Yes	No
SORTS (Equipment)	Percentage of time a unit spends in C3 for equipment	1977-94,	WWMCCS	Yes	No
SORTS (Equipment)	Percentage of time a unit spends in C4 for equipment	1977-94,	WWMCCS	Yes	No
SORTS (Equipment)	Percentage of time a unit spends in C5 for equipment	1977-94,	WWMCCS	Yes	No
Number of days spent on maintenance	CNA's ship employment histories database breaks maintenance into a full list of activities—both planned and unplanned	1977-94, monthly	EMPSKDs	Yes	No
Time spent in I-level maintenance	Intermediate maintenance time refers to the amount of time a ship is in intermediate maintenance	1977-94, monthly	EMPSKDs	Yes	Yes
Casualty Reports CASREPs)	Number of C3/C4 CASREPs that were reported	1977-94,	CASREP database	Yes	Yes
Casualty Reports CASREPs)	Total number of CASREPs reported	1977-94,	CASREP database	Yes	Yes
Casualty Reports (CASREPs)	Number of C3/C4 CASREPs that are being worked on	1977-94,	CASREP database	Yes	No
Casualty Reports (CASREPs)	Percent of reported CASREPS that are C3 and C4	1977-94,	CASREP database	Yes	Yes
Casualty Reports (CASREPs)	Average maintenance time to fix a C3/C4 CASREP	1977-94,	CASREP database	Yes	No
Casualty Reports (CASREPs)	Average time to fix a C3/C4 CASREP that due to supply (awaiting parts)	1977-94,	CASREP database	Yes	No
Casualty Reports (CASREPs)	Average time to fix a CASREP due to supply	1977-94,	CASREP database	Yes	Yes
Casualty Reports (CASREPs)	Average time spent fixing a CASREP due to maintenance	1977-94,	CASREP database	Yes	Yes
Casualty Reports (CASREPs)	Percent of time free of C3/C4 CASREPs	1977-94,	CASREP database	Yes	No
Casualty Reports (CASREPs)	Percent of new CASREPs that are C3 or C4	1977-94,	CASREP database	Yes	Yes
OPPE inspection rates	Number of ships that underwent an OPPE inspection compared to those that failed	1977-94, monthly	EMPSKDs	Yes	No
Age of ship	Number of months since the ship was commissioned	1977-94, monthly	Jane's	Yes	Yes

Table 10. Material condition indicators of ship readiness

Indicator	Definition	Data availability	Source	CNA archives	In CNA model[a]
Ship conversion funding	Refers to construction of new ships plus certain modification and overhaul for nuclear refueling of nuclear-powered ships and subs, as well as service-life extensions	1977-94, annual	Budget documents	Yes	Yes
Maintenance funding	Refers to the cost of scheduled depot maintenance support of ships in the operating forces (lagged)	1978-94, annual	VAMOSC	Yes	Yes
Modernization funding	Refers to the cost of installing ship alterations and improvements (lagged)	1978-94, annual	VAMOSC	Yes	Yes
Small equipment funding	Cost of all Navy Stock Account (NSA) type items that are not classified as consumables or repair parts	1978-94, annual	VAMOSC	Yes	Yes
I-level maintenance costs	Cost of labor expended by a Shore Intermediate Maintenance Activity (SIMA) on the repair and alteration of a ship	1978-94, annual	VAMOSC	Yes	Yes
Rework funding	Refers to the costs of overhaul, rework, or repair of major ordnance equipment (lagged)	1978-94, annual	VAMOSC	Yes	Yes
Engineering and technical service costs	Refers to the cost of engineering and technical services provided to the ship other than during I-level maintenance or depot availabilities	1978-94, annual	VAMOSC	Yes	No
Nonstrategic, weapons procurement	Costs associated with procurement of nonstrategic, tactical missiles, satellites, torpedoes, guns, and other weapons, ordnance, spare parts, and support equipment	1977-94, annual	Budget documents	Yes	Yes
Propulsion system	Percentage of ships that use gas turbine engines	1945-94	Jane's	Yes	No
Propulsion system	Percentage of ships that use steam engines	1945-94	Jane's	Yes	No
Propulsion system	Percentage of ships that use nuclear-powered engines	1945-94	Jane's	Yes	No

a. Refers to whether a specific indicator is in CNA's final form, regression model (meaning that it has been found to be statistically associated with a predictor variable contained within the model).

Table 11. Supply indicators of ship readiness

Indicator	Definition	Data availability	Source	CNA archives	In CNA model[a]
SORTS (Supply)	Percentage of time a unit spends in C1 for supply	1977-94, monthly	WWMCCS	Yes	Yes
SORTS (Supply)	Percentage of time a unit spends in C2 for supply	1977-94,	WWMCCS	Yes	No
SORTS (Supply)	Percentage of time a unit spends in C3 for supply	1977-94,	WWMCCS	Yes	No
SORTS (Supply)	Percentage of time a unit spends in C4 for supply	1977-94,	WWMCCS	Yes	No
SORTS (Supply)	Percentage of time a unit spends in C5 for supply	1977-94,	WWMCCS	Yes	No
Casualty Reports (CASREPs)	Average time per quarter spent fixing a C3/ C4 CASREP that occurred because of supply	1977-94,	CASREP database	Yes	No
Casualty Reports (CASREPs)	Average time fixing a CASREP that was due to supply	1977-94,	CASREP database	Yes	No
Casualty Reports (CASREPs)	Average time per quarter spent fixing any CASREP that occurred because of maintenance	1977-94,	CASREP database	Yes	No
COSAL effectiveness	The probability that a requested item is stocked onboard whether or not it is available when requested	1977-94, quarterly	Ship's 3M System	Yes	No
Net effectiveness	The probability that a stocked item is onboard when requested	1977-94, quarterly	Ship's 3M System	Yes	No
Gross effectiveness	The probability that any requested item is onboard when needed	1977-94, quarterly	Ship's 3M System	Yes	Yes
Repair parts funding	Refers to the cost of repairable repair parts consumed by the ship	1978-94, annual	VAMOSC	Yes	Yes

a. Refers to whether a specific indicator is in CNA's final form, regression model (meaning that it has been found to be statistically associated with a predictor variable contained within the model).

Table 12. Training indicators of ship readiness

Indicator	Definition	Data availability	Source	CNA archives	In CNA model[a]
SORTS (Equipment)	Percentage of time a unit spends in C1 for training	1977-94,	WWMCCS	Yes	Yes
SORTS (Equipment)	Percentage of time a unit spends in C2 for training	1977-94,	WWMCCS	Yes	No
SORTS (Equipment)	Percentage of time a unit spends in C3 for training	1977-94,	WWMCCS	Yes	No
SORTS (Equipment)	Percentage of time a unit spends in C4 for training	1977-94,	WWMCCS	Yes	No
SORTS (Equipment)	Percentage of time a unit spends in C5 for training	1977-94,	WWMCCS	Yes	No
Time spent training	CNA's ship employment histories database breaks training into a full list of activities	1977-94,	EMPSKDs	Yes	No
Training funds	Total money spent Navy-wide on training activities	1977-94, annual	Budget documents	No	No
Number of exercises	Number of major and minor exercises ships conduct annually	1980-94, annual	Budget documents	No	No
Ammunition funding	Refers to the costs associated with expendable stores, consumed by the ship, which are purchased from procurement appropriations	1978-94, annual	VAMOSC	Yes	No
Professional training costs	Refers to the cost of C- and F-course training for the ships crew to enable them to perform assigned maintenance and operational tasks	1978-94, annual	VAMOSC	Yes	No

a. Refers to whether a specific indicator is in CNA's final form, regression model (meaning that it has been found to be statistically associated with a predictor variable contained within the model).

Table 13. Glossary of sources

Abbreviation	Formal name	Definition	Source:
CASREP	Ship Casualty Reports Database	The Navy's casualty reporting system provides a method for reporting equipment failures and the effect of these failures on the ability of the reporting unit to perform its mission.	Navy Ships Part Control Center (SPCC)
EMR	Enlisted Master Record	The EMR consists of personnel files maintained on all active duty Navy enlisted personnel. CNA receives a snapshot of the file every quarter and maintains it as a source of data for many Navy manpower and personnel studies.	Navy Military Personnel Command (NPC-135)
EMPSKDs	Ship Employment Schedules	EMPSKDs are prepared and published quarterly. They provide detailed information on the utilization and status of naval forces for planning, control, and historical purposes.	N311
Jane's	Jane's Fighting Ships	Country by country data on the fleets of the world, their composition, and their capabilities	Jane's Information Group, Ltd.
Ships' 3M System	Navy Material Maintenance Management (3M) System	This database contains maintenance action data on Navy ships.	Navy Ship Parts Control Center (SPCC)
VAMOSC	Visibility and Management of Operating and Support Costs Management Information System	VAMOSC contains detailed, historical information on ships operating and support costs. It is aggregated by ship on an annual basis. There is also a VAMOSC-air version of the database for Navy aircraft.	Naval Center for Cost Analysis (NCCA)
WWMCCS	World-wide Military Command and Control System	The system that provides the means for operational direction and technical administrative support involved in the function of command and control of U.S. military forces (Joint Pub 0-2).	Joint Staff
Budget documents	DON Justification of Estimates Book (attachment to annual budget submission), 1976-94, and The Future Years Defense Program: Historical Summary of Program Element Detail, 1962-94	Sources contain assorted data on Navy force structure and associated equipment, personnel, and operating costs.	N/A

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